Innovative automated unloading of parcels

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Abstract

In modern powerful logistics the courier express and parcel market (CEP) is of special interest. Same-day and one-hour-delivery are demanding for providers to efficiently handle large piece goods volumes nowadays even in bulk form. Loading and unloading of vehicles within the CEP-sector is the most crucial part in the whole process, with sorting and conveying working sufficiently nowadays.

The authors describe a completely new solution to unload vehicles, developed by simulation, tested in laboratories and implemented in real processes. The device is to be installed in trailers/trucks with minimal effort and connects automatically to a stationary device within a typical CEP-hub at a loading/unloading bay. Identifying bulky amounts of piece goods therein was proven with RFID. Furthermore the within this bmvit funded project developed prototype "EAGLE" was realized within the laboratories at Graz University of Technology. Project partners from RFID-business (TAGpilot) as well as from parcel business (Österreichische Post AG) were engaged in the whole project. Lab tests showed great performance and a decreasing unloading time, compared to the actual manual unloading, by 70%.

The contribution outlines main steps within the development, where an extensive use of simulation methods powered a broad variation in design. Specially engineered methods for simulating motion behaviour of large amounts of piece goods were the scientific output of the project. The lab tests are described by depicting innovative measuring methods for bulky piece goods. Furthermore broad fields of different parcels and piece goods were used to analyse their behaviour at the virtual prototype for DoE. A performance analysis concludes the paper outlining possible fields of installation in the CEP-sector.

Keywords: truck unloading; bulky piece goods; simulation of parcel behaviour.

1. Motivation and state of the art

Due to the current state of technology trucks, which are delivering parcels (piece goods) in the parcels-, courier- and express market segment, are unloaded manually. Piece goods can be found a sorted or a stacked way, as well as disordered form inside containers or transporters. Frequent lifting of heavy weights and unergonomic motion sequences are leading to loss of time and bad physiological working conditions during the unloading process. Until now, finding an exact description of the physical behaviour of big amount of parcels inside a container, was really complex. Here interaction between parcels as well as interaction between parcels and package handling systems occurs. In many cases, building a huge number of expensive prototypes and testing them during real situations, was the only possibility to find a way to optimize devices and equipment. This means that technical machinery, which would be able to handle a big number of parcels by using the dynamic behaviour of bulk, represent a speciality in field of material handling. Different device manufacturers and research institutes tried to find different

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ways and variants to solve the problem of singulation by disarranging bulk (3D to 1D). So far none of these approaches led to an absolutely satisfying solution (Table 1). Nowadays criteria for optimal unload- /separation process like

- cost-efficiency
- high throughput of separated piece goods
- space-saving
  (usage of existing plant layout)

- safety and health of workers (ergonomics)
- no mechanical damage of the piece goods
- high automation rate
- fulfilling of constraints (acc. separation, distance und orientation of the goods),

are not met in a sufficient way. Due to that mentioned disadvantages of current technology, manual unload processes are still state of the art, aside of few expectations.

Table 1. state of the art – Unloading and separation of big amount of parcels.

method or device	type	source	comment
Manual separation (supported by movable telescopic conveyors)	**unloading** 3D to 1D		Separation mostly takes place during unloading
Rubus – Unloading by winding of belts	**unloading** 3D to 2D	Silog News (02/2013) - Siemens company publication US2013/0230373A1	Technical extremely complex system / only suitable for container size
revolving conveyers inside the container	**unloading**	http://www.ancra.nl/	High need of space and equipment inside the container
Automated lifting (robot with camera system)	**unloading** 3D to 1D (status of development)	Echelmeyer, W. (2008). EO2059467B1. Deutschland Robotik Logistik (2013) www.robotik-logistik.de	Very low throughput / expensive equipment
Accord Singulator	**separation** 3D to 1D	http://www.fivesgroup.com	High need of space / complex construction
Crisplant Automatic Parcel Singulator	**separation** 3D to 1D	www.beumergroup.com	High need of space / complex construction
Linear Singulator Flow Controller (separation an orientation by angular rolls)	**separation** 2D to 1D	Jodin, D., & ten Hompel, M. (2012). Sortier- und Verteilsysteme	Very high need of space compared to separation performance
Accord Singulator (different section of conveyers and roll elements)	**seperation** 2D to 1D	Jodin, D., & ten Hompel, M. (2012). Sortier- und Verteilsysteme	Only suitable for small parcels and low throughputs
Siemens VisiCon (camera system with matrix of separately driven conveying elements)	**seperation** 2D to 1D	Siemens AG Corporate Communications and Government Affairs. (Januar 2009)	Technical extremely complex system
Using of automated push rods (camera system with matrix of separately driven rods)	**seperation** 2D to 1D	Grund, H.J. (2002). EP 1105327 A2. Deutschland	High need of number of actuators
Segments with different section speeds – combined to barriers, slopes etc…	**separation** 3D to 2D	Fives Cinetic. (2013). www.fivesgroup.com	Process reliability still very low

It can be outlined that state of the art (table 1) should not be relevant for the desired concept or invention. Therefore, patents seem particularly relevant, which means for evaluation patentability has been given closer consideration[2].

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[2] US 5,915,911A - Pickup truck unloader, US 2010/0296902A1 - Apparatus for loading and unloading loading units, EP0342636A2 - Unloading mechanism for trucks and trailers, US 4,629,390A - Truck bed unloader, US2012/0087770A1 - Automated Bed-loaded Container Unloader and Method

2. problem, innovative content and system advantage

In logistic chains the processes of loading and unloading goods are very often appearing as a bottleneck Thinking of increasing number of deliveries at parcel distribution centres, this leads to a claim for higher and higher throughputs (see Biek (2014) and Kearney (2011)). Main reason for this is the increasing number of online-orders, most of them consisting of small batches (see Deutsche Post AG (2104)). Before reaching the last step of delivering to the customer, parcels need to be transported to the distribution centres by transportation vehicles (e.g. trucks, …) within huge bundled package pools. After unloading and separation, the following steps are identification, sorting and distribution inside the distribution centre. As mentioned before, bottlenecks of this process chain are the processes of unloading and separation of the parcels, which is mostly done manually by workers (unload time for each container by one worker approx. 1 to 2 hours), as well as inserting the parcels into the sorting devices, which are facing the high automation rate that can be found in the rest of this logistics chain. Even in other distribution centres, regardless of the size of the centre, the same problems can be spotted, due to the similar fundamental function of all distribution centres (Jodin and ten Hompel (2012)). At the process of manual unloading, as it is today usually performed, the maximum of performance of one worker at CEP-branch stands between 800 and 1.000 parcels per hour. Due to required increase of performance at following processes of the logistics chain, claimed throughputs are increasing to 3.000 to 4.000 parcels per hour and unloading bay. This high throughput can be reached with using manual unloading just by increasing personal by the factor of 3, which also means the need of increasing the number of unloading bays and expensive structural changes.

One possibility to deal with that problem and increasing the throughput, will be the development of a new technique for automated unloading and separation of a big amount of parcels. Such a device needs to be able to shorten unloading time by a factor of 10 which would enable the reachability of the goals for the throughput. Simultaneous no additional workers are needed to fulfil the unloading process manual. Innovative ideas allow the fulfilment of the objectives to a flexible, high performance and automated unloading process for bulky piece goods.

Such requirements include:

- dispatch of vehicles of different forms and sizes
- as low technical complexity as possible (reliability, low investment costs for user)
- flexible usability for existing plants (no expensive modifying of infrastructure)
- largely unchanged transportation vehicles (low or no modification)
- no need of supported energy for a device inside the transportation vehicle, in order to
- not discharge vehicle's battery during unloading process
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Technical advantages should be:

- faster unloading processes compared to manual unloading
- soft-smooth handling / low mechanical impact
- no need of supported energy inside the transportation vehicle
- simple and intuitive operation / no need of special training
- possibility of processing vehicles of different width at the same unloading bay
- compact system and low or no need of modification of the transportation vehicle
- no need of modification and rebuilt of the unloading bay
- minimal moveable parts, sensors or actuators and usage of standard components
- low installation effort
- low energy consumption (stationary unit)

The introduced development project EAGLE is essentially based on theoretical pre-work by Fritz (2016) for simulation of big amount of parcels and systematization of separation technologies.

3. Methods

This complex plan for unloading big amount of bulky piece goods requires different methodical approaches (overview in Fig. 1), in order to develop this device in the most efficient way, which includes the virtualisation of as much development processes as possible. This is the only way to be able, on one hand to handle this complexity and on the other hand find reachable solution at all. There are many well-known methods with simulation in the development processes in field of logistics engineering introduced by Landschützer (2016), which are already leading to success of virtual engineering in this branch - just like in other branches where that methods are also established (e.g. automotive).
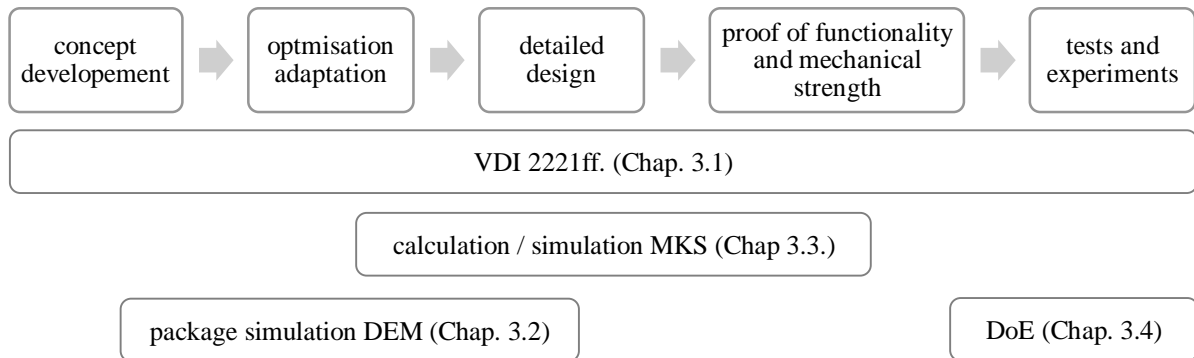

Fig. 1 procedure and methods during developement of EAGLE

3.1 methodical design

VDI 2221(1993) provides a framework for the methodical development of the unloading system (rough and detailed design). This general problem solving method, which provide procedures, steps, tools and methods for designing technical systems, gives support for determining of separated functions including defined system borders (Fig. 2) and for identifying detailed solutions for all of these separated functions on material-, energy- and information level (systematic problem-solving methods by using morphology and decision-making procedures by Pahl and Beitz (2007)). Therefore Fig. 2 shows the problem "parcel singulation" in such an abstract way, that enables the finding of principle solutions for that separated functions. Combined to additional systematizations for automated unloading (interface "WE" at Fig. 2) this leads to a final device with is systemised of modules, which principle solutions has been found for.
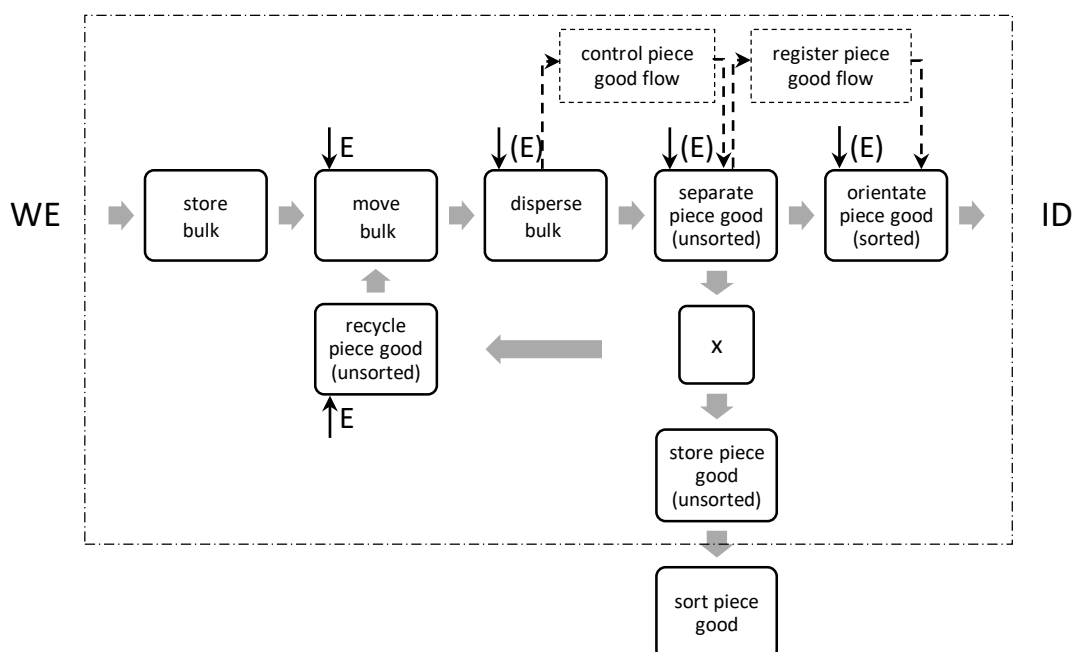

Fig. 2 separated functions of package separation

3.2 Method for simulation of big amount of parcels (DEM)

At ITL (Institute of Logistics Engineering at Graz University of Technology) a by Fritz (2016) developed knowledge base for simulation of big amounts of parcels enables an efficient way of developing package-handling technologies. Therefore simulation methods from different disciplines were examined and adapted according to the present problem areas. Concepts based on discrete-elements-method (DEM) seemed to be highly promising. By using that DEM methods new possibilities of displaying parcels were developed. Special emphasis was placed on finding and determining the realistic physical parameters of the parcels (coefficient of friction, contact stiffness,…) by doing tests with real parcels by Fritz et al. (2013). The biggest advantages of using DEM methods are the positive trend of simulation time according to increasing number of parcels (in contrast to MKS) and the easy way to implement new geometries of models. This DEM method enables a time efficient way to simulate big amounts of parcels and their interaction with handling devices as described by by Fritz et al. (2013). This means DEM can be used in early development stages to find suitable strategies of separating parcels. DEM also provides possibilities to identify and determinate stresses on the piece goods, in order to minimize the risk of mechanical damage for a certain technical solution at an early stage of development.

Furthermore DEM can be seen as a powerful tool for optimizing devices according to Dallinger et al. (2012). For instance, physical parameters (e.g. belt's speed) or geometrical parameters can be adjusted by using simulations based on DEM methods. This means a reduction of number of prototypes and test rigs to a minimum. By doing this customer's needs and wishes for the devices can be fulfilled by relatively little effort. Without using any of that simulation methods, development of devices used for manipulate goods in bulk, would not be possible in an economic sense.

3.3 Multi-body simulation (MBS) and finite element method

Further methods, like multi-body simulation (MBS) and finite element method (FEM), are used for proofing of functions, mechanical strength and performance. Also that CAE methods as well as DEM are able to ensure controllable and fast project progress. Advantages of using CAE in that projects are:

- Identifying of damage mechanisms und critical component areas in an early stage of development.
- Analysis of operational stability and resonant oscillations
- Weight optimization of the components (lightweight constructions has particular relevance for the mobile part of the system)
- Optimization of components during dynamic procedures (e.g. positioning of the stationary part of the system before connecting)

3.4 Design of Experiments – DoE

DoE is used as a method for efficient planning and evaluation of tests and experiments with the Unloading system. DoE is able to identify a big amount of different effects and impacts on the system, by using just the least possible number of tests. High approachability, efficiency, stability and a clear presentation of the results are the biggest benefits of DoE usage according to Siebertz (2009). Following chart Fig. 3 shows the influence to the unloading system and the expected results from the tests.
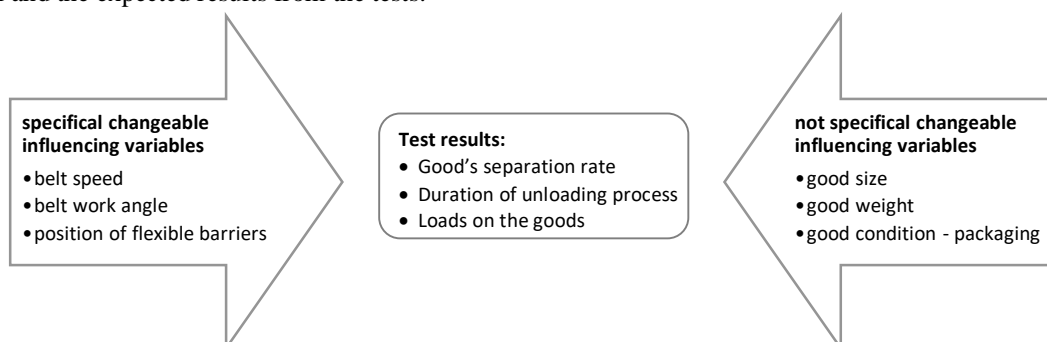
specific changeable influencing variables
- belt speed
- belt work angle
- position of flexible barriers

Test results:
- Good's separation rate
- Duration of unloading process
- Loads on the goods

not specific changeable influencing variables
- good size
- good weight
- good condition - packaging

Fig. 3 DoE – influencing variables on the system and expected results

4. Results of development and design

4.1 Requirements analysis

The most important aspects were the composition of piece goods (cargo inside transport vehicle) as well as the situation at unloading bay and the process sequences at distributional centres. Furthermore possible requirements and constraints regarding to handling of piece goods (e.g. maximum drop height) were implemented according to the terms of conditions from Österreichische Post AG[3] as well as requirements according to the well-known Maschinenrichtlinie 2006/42/EG[4] has been setting as frame conditions for development. As a target for the performance of the unloading system a minimum throughput of 3.000 parcels per hour was set. The analysis process of piece goods composition included approximately 400.000 datasets from Österreichische Post AG, however goods were split up into direct sortable piece goods and on the other hand goods which are requiring an additional auxiliary tray. More than 90% of all goods can be determined as direct sortable piece goods (parcels above the minimum dimensions).
By doing abstractions using VDI 2221 (acc. Chapter 3) search for all principle solutions, including evaluations according to the requirements, came up with the result of a two-part concept (Fig. 4) which will be explained in detail below.

4.2 Mobile unit

Development process of the mobile part of the unloading system (located on the transport vehicle) has been faced to the key goal of cost-efficient design. The most cost efficient way should be reached by waiving of actuators as far as possible in order to reduce component costs as well as modifying effort on transport vehicles by using passive elements. The additional requirements for minimum of weight and space were crucial for systematic and methodical search for solutions.
Procedure of methodical design (concept phase) in first step came up with different possibilities to realize pulling a carrier belt, which is located on the transporter, out of it and retract it again by using an energy store system. A special attention has been put on the long distance to pull out (more than 12 m) as well as an almost constant retracting force. Due to as cheap as possible design a spring energy store was defined as a basic design element for the system.
The result of development phase included a drum which is driven by a specialized spring mechanism, enabling the fulfilment of all mentioned requirements. Principal design is shown at Fig. 4, however that picture already shows an assembled state located on swap body bridge.
For selecting the carrier belt the main requirements of lowest possible weight, low friction coefficient between loading area base and belt as well as sufficient strength could be fulfilled. Typical piece goods characteristics and bulk composition (Chapter 3) were base for determining expectable loads. For choosing suitable belt materials, friction tests were hold in laboratory.

4.3 Stationary unit

The stationary part of the unloading system is being permanently installed at the unloading bay. During the process of bulk unloading, the stationary part will be connected to the mobile unit which is located inside the transporter. It is very important that the stationary unit gets positioned exactly, however gaps or angular offsets between stationary unit and the transport vehicle need to get compensated. Fig. 4 shows on top a total view of the whole unloading system when it is disconnected. Underneath that the picture figures out a schematic view of the whole coupled system (mobile part as a retreat unit (4), carrier belt (2), coupling (6), components of the stationary part (7, 8, 11)) can be found.

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[3] https://www.post.at/footer_ueber_uns_agb.php
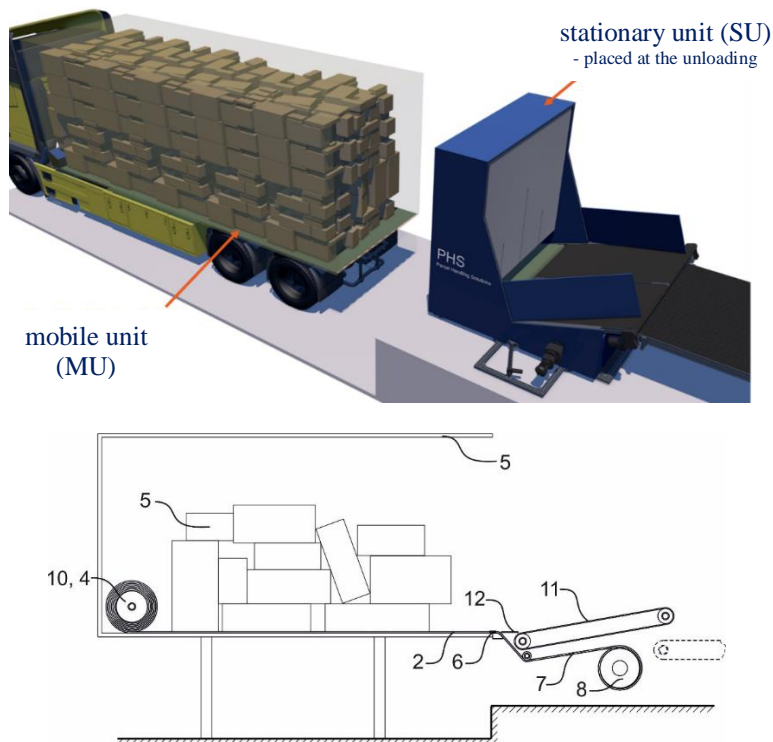[4] http://www.maschinenrichtlinie.de/fileadmin/dokumente/2006-42-EG_maschinenrichtlinie_de.pdf

Fig. 4 Stationary unit and mobile unit of the unloading system EAGLE[5]

Simulation of dynamical behaviour of the piece goods by using discrete-elements-method (DEM – Chapter 3.2 and Fig 5.a) in early stages of design process was another important key step in order to gain success. All developed possible variants and concepts of the unloading system were modelled for simulation and all significant design parameters were varied. For modelling the variety of piece goods a reprehensive reference spectrum was generated by using k-means-procedure (procedure for generating clusters) basically using data from requirement analysis (Chapter 4.1)

By means of that progressed simulations, quality of separation during the unloading process could be determined, however parameters, which were optimised by using statistic test planning were included into the following design phase.

Fig. 5 exemplary shows the simulated unloading and separation process, which is used for defining optima of belt speed and incline of the belt conveyer. Therefore the graph on the right side of the picture (5.b) depicts the number of parcels, lying on top of each other after the separation process. In this graph a flat topology means a good outcome of separation and singulation processes. Results of these simulations especially showed that bigger inclination angle of the conveyer belt leads to a positive effect. Also a big difference between speed of conveyer belt and speed of carrier belt has positive impact on the quality of separation process. All in all, the procedure of virtual optimizing has showed up as a very beneficial way of optimizing compared to the purely empirical variant of using test rigs. Such extensive testing, which was essential for the development, would not be able to perform on realised prototypes in that way.

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[5] EP 3061648A1 Unloading system for unit load

container

control area

parcels

horizontal carrier belt

tilted conveyer belt

v2=0.5, alpha=10, my=0.4

number of parcels

time [s]

measure point

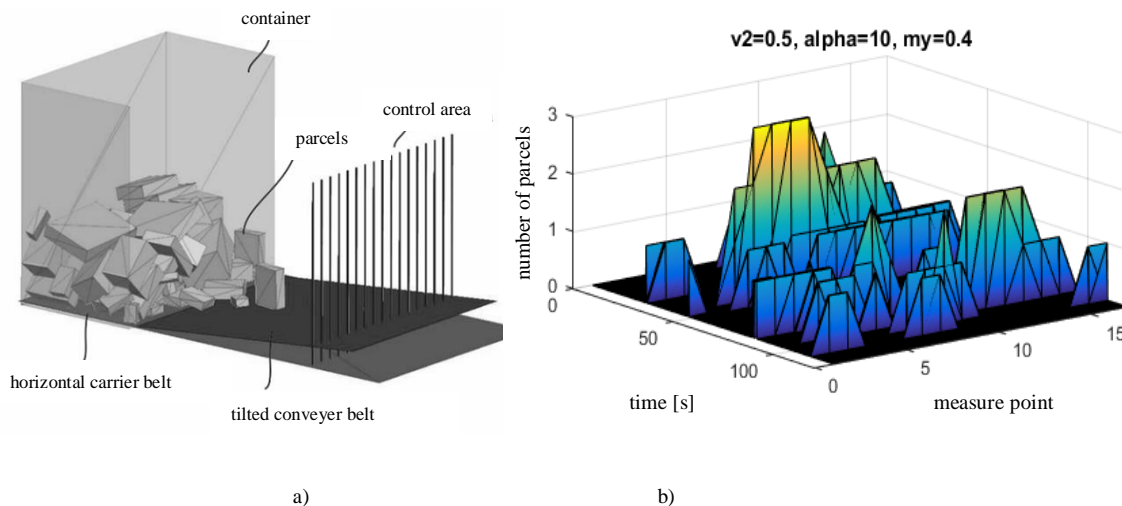a)   b)

Fig. 5 (a) DEM-simulation of the unloading system EAGLE (b) evaluation of separation quality at control area

Based on that showed results of the early development stage, the stationary unit of unloading system was further developed, components were calculated, designed and chosen as well and production drawings were generated. The finished overall prototype includes possibilities for movements in vertical direction (lifting function for height compensation) as well as in the horizontal direction. For moving the stationary unit actuators based on a plane Stewart-Gough-platform, which is able to perform translation as well as rotation in plane, has been installed. According to that possible moving axis, the prototype is able to adjust and position itself fully automated referenced to the transport vehicle.

During the unloading process the connected belt get pulled out of the swap body (Pos. 5 in Fig. 4) underneath the conveyer belt (black) were it gets rolled up. A tunnel prevents parcels from dropping during the whole process, while deflector shields are uniting the piece good flow.

Simultaneously a concept for controlling including positioning of the stationary unit as well as connecting, pull-of and disconnecting processes, has been developed and implemented. An optical detecting system which is able to locate the transport vehicle, by using 2D codes, was provided for realizing an automated connecting process of the stationary unit to the mobile unit. Additionally, ultrasonic sensors were used to detect possible angular errors between stationary unit and transporter in order to be able to compensate them in following steps.

4.4 Identification unit

The aim of this step was to analyse the feasibility of using bulk parcel identification during an automated unloading process. Therefore special attention was payed for reliability of RFID systems combined to their restriction. Following points need to be clarified and checked:

- In which way the unloading process needs to be performed (rate of separation) in order to ensure identification?
- Where the RFID readers need to be placed?
- Which are suitable tags (power supply, needed space, type, storage capacity, …)?
- Which frequency range can be handled (influencing range and selectivity)?
- Are there any additional required features (e.g. encoding)?
- Which data stream modes and coupling methods are suitable?

In order to fulfil that tasks, a concept for bulk identification by RFID (Radio-Frequented-Identification) has been developed and tested. Different sized parcels had been labelled by an UHF label in order to validate that test runs. The used wide-range-antennas has been installed above the belt conveyer, which enables an identification of parcels during unloading process.

During test runs the number of readings of each different parcel has been documented. Fig. 6 shows exemplarily a 10-second-section of recorded data during test run. In that graph each point stands for one reading action and each colour means one specific parcel.
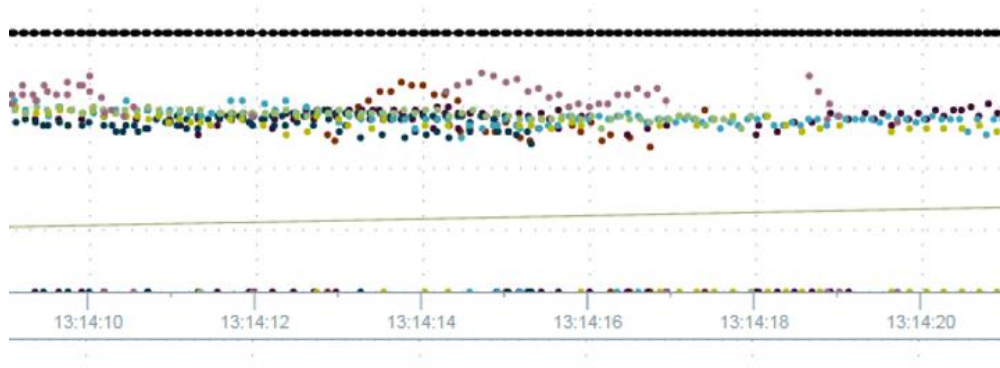
Fig. 6 number of readings of RFID-tags during unloading process

5. Evidence of functionality

Developed parts of the whole unloading system were assembled and calibrated at ITL's experimental hall (lab). Fig. 7 shows how the prototype looked like. An additional installed flexible barrier protected the parcels from dropping from a big height in conveying direction. Furthermore, the picture shows the used yellow-coloured swap body, as well as the wide-range-antennas (RFID). The mobile unit of the unloading system has been installed inside the swap body in order to be able to get the test scenario as realistic as possible.

Fig. 7 prototype EAGLE in experimental hall at ITL

Tests for functions and processes were performed at ITL's lab. Field studies at distribution centres were refused, due to safety issues, because of prototype's missing certifications (work safety). Nevertheless, realistic situation during testing was very important, therefore the used transporter was part of the Österreischische Post AG's fleet, by whom the test got supported with over 1.000 specialised test parcels. During different tests according the process requirements, following situations have been tested.

- Different filling rate inside the swap body bridge.
- Different loading strategies (chaotic, stapled, mixed)

- Variation of unloading speed
- Changeable composition of the piece good (parcels, polybags, cylindrical objects, different sizes, flats)

For basic analysis of the different processes videos from the inside as well as from the outside have been taken during unloading process. Based on that videos the unloading process and separation has been evaluated, damaged parcels have been counted and unloading time has been taken. Fig. 8 a-c shows some snapshots taken during unloading a typical unloading process.
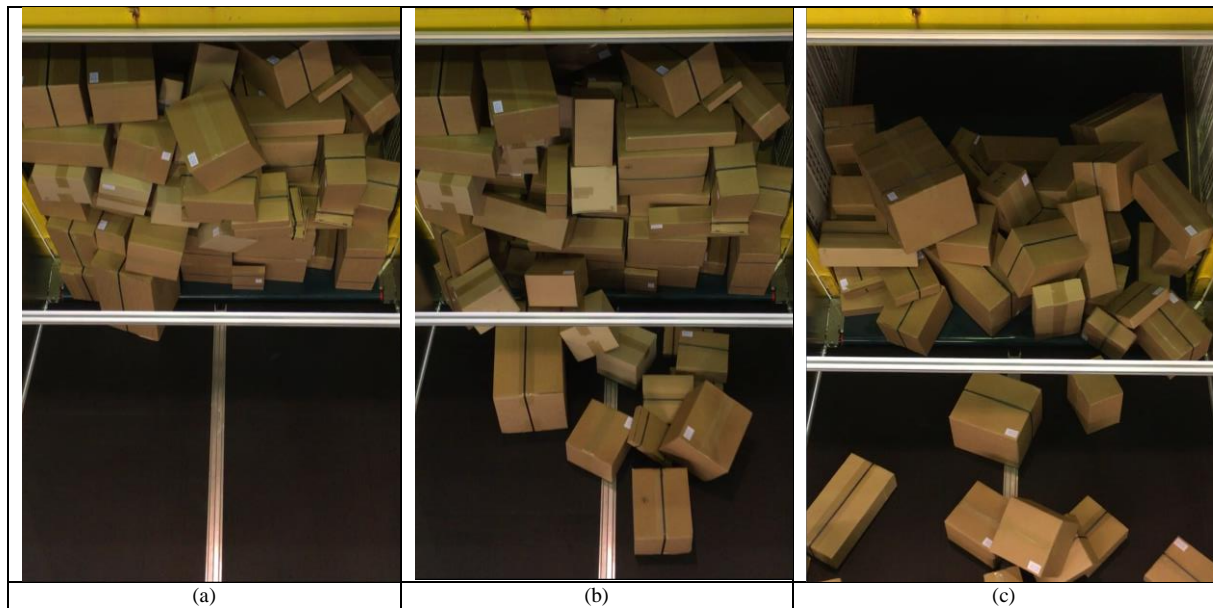
| (a) | (b) | (c) |

Fig. 8 temporal sequence of unloading and separation process (a) 0 s (b) 7 s (c) 200 s

6. Outlook and acknowledgement

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