Urban Consolidation Centers – an Analysis of Internal Processes Using Discrete Event Process Simulation

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***Abstract*— This study addresses the spatial constraints posed by urbanization and population growth in cities. It evaluates different types of urban consolidation centers to improve urban logistics. Design parameters are identified through literature review, and an evaluation methodology is developed. Simulation models are created for each center type, integrating the evaluation approach. The approach is validated in a case study in Munich, using real-life data. Simulation results analyze key performance indicators and provide recommendations for optimizing logistics and economic aspects in urban consolidation center planning. Efficient options include roll containers, electric pallet trucks, Last In – First Out storage, and gloves with integrated identification devices.**

Keywords – Cargo bikes; City logistics; Discrete-event simulation; Identification technologies; Urban consolidation centers.

I. INTRODUCTION

The volume of Courier, Express, and Parcel (CEP) shipments grew by 11.2 % to 4.51 billion shipments from 2011 to 2021. Annual growth of 4.7 % is expected up to 2026 [1]. Apart from extraordinary events, such as the COVID-19 pandemic, this is mainly due to changing consumer behavior, increasing urbanization, and growing demand for e-commerce products [2]. Online retail poses new challenges for urban delivery traffic, as more and more small shipments are to be delivered to customers more quickly [3]. To that end, city logistics is confronted with challenges similar to those industrial material flow systems are confronted with [4]. In addition to that, special services, such as same-day or same-hour delivery are gaining in importance [5]. Environmental protection measures and efficiency improvements are urgently needed. The concept of Urban Consolidation Centers (UCCs), which are located close to delivery areas, enables the distribution of goods flows and route-optimized delivery [3]. UCCs serve as transshipment points for environmentally friendly vehicles and as interfaces for alternative delivery concepts [6]. Simulation techniques help plan and optimize UCCs in neighborhoods with a relevant usage potential [7]. This article presents a simulation-based approach for the analysis of UCCs and the identification of feasible design premises.

The work is structured as follows: In Section II, the state of the art regarding design and operations of UCCs is presented and subsequently, research objectives are derived. In Section III, an approach for setting up simulation-based UCC analyses is presented and implemented with a case study example. Section IV concludes the work by summarizing the results and identifying limitations and potential future research work.

II. STATE OF THE ART AND RESEARCH OBJECTIVES

A. *Urban consolidation centers for parcel distribution*

UCCs serve as transshipment hubs for high-volume shipments in densely populated areas, facilitating the flow of goods between shippers or recipients and regional distribution centers. Generally, transportation is provided by trucks in classes ranging from 3.5 to 12 tons.

Shipments are pre-sorted at regional distribution centers and typically consist of low-weight, low-volume goods delivered in high-density areas (see Figure 1). UCCs are supplied from CEP service providers' regional centers in the morning, using roll containers or pre-sorted boxes. UCCs can be either stationary or mobile, using pre-existing real estate or swap bodies/trailers to create temporary hubs. Mobile UCCs are transported to and from the established location by truck [8].

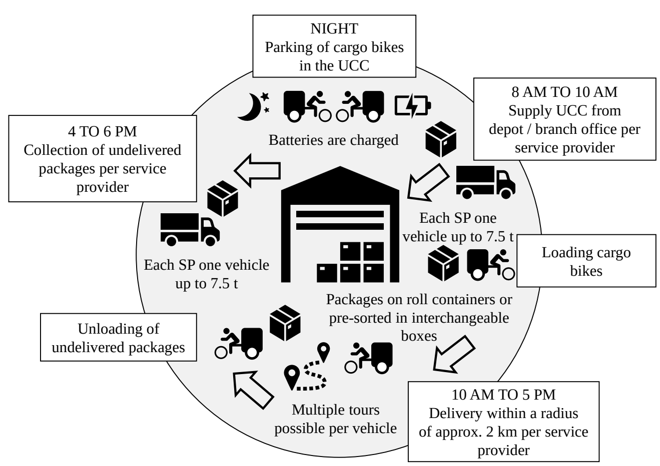

Figure 1. Operating scenario for a multi-user UCC, based on [8].

B. *Quantitative methods: discrete-event process simulation and methods-time measurement*

Discrete-Event Simulation (DES) examines event-driven process chains using multiple scenarios [9]. Transferring gained knowledge to the real-world system requires minimal differences between the initial system and the model [10]. System variants are compared and evaluated based on different criteria. This paper maps and models the material flow system in UCCs using DES, following five essential steps: Task analysis, model design, implementation, verification, validation, and application [11]. Methods-Time Measurement (MTM) determines standardized process times by breaking down human motion into steps [12]. It quantifies manual processes in UCCs, assisting in DES model parameterization by adding relevant partial times of basic movements to determine total activity time [13].

C. *Storage equipment: handling systems and identication technologies*

Two types of load carriers in UCCs are considered in this work: Roll containers and Euro pallets. Roll containers are self-driven with wheels, requiring no handling equipment. Euro pallets are handled using manually operated or electric pallet trucks [14]. Different identification technologies in warehouse logistics simplify package sorting and recognize package information [15]. They can be condensed to four representative main types of identification technologies, which are the following: Smartphone, glove with built-in scanning device (ID glove), stationary camera and RFID scanner. Cameras and RFID scanners require special workstations, while smartphones and ID gloves provide mobile solutions carried by workers during sorting, eliminating the necessity for separate workstations [16].

D. *Parcel sorting and storage operations*

Efficient storage systems prioritize fast access, short transport and walking distances and organized structures [17][18]. For UCCs, a row storage is the most common variant. It allows fast access and moderate investment costs. Thus, in the following, a row storage scheme is used for all configurations. Storage strategies aim to minimize distances, maximize capacity utilization, and prevent obsolescence. Besides First-In – First Out (FIFO) and Last In – First Out (LIFO), other strategies, such as optimizing service routes and combining orders, can be applied [16][19].

E. *Research objective*

The impact of UCCs on urban logistics has been studied in Barcelona (Spain) and Belo Horizonte (Brazil), considering economic and ecological factors [20][21]. Various methods have been developed to determine locations and identify factors affecting depot operations for enhanced collaboration among stakeholders [22][23][24][25]. Moreover, UCCs were evaluated for business opportunities and collaboration using Key Performance Indicators (KPIs) and DES models in a case study in Greece [26]. Also, the effectiveness of traditional delivery trucks and cargo bikes for parcel delivery was compared and assessed using the DES approach and agent- based simulation [27].

The previous research is strongly focused on the handling and delivery process and the general cooperative use of UCCs, examined from the macro perspective. The simulation-based investigation and evaluation of material flow and storage strategies, as well as their influence in combination with further configuration parameters within different UCC types is not considered accordingly. This results in two research objectives that this work addresses:

1) How can different UCC types be evaluated under variation of relevant layout parameters, as well as material flow and storage strategies by means of DES?

2) Which recommendations can be derived for the planning and dimensioning of UCCs, the processes to be carried out and the selection of identification technologies?

III. MODELING

In the following subsections it is explained how UCC operations are modeled using a DES approach, including the selection and implementation of different parameters.

A. *Concept of an evaluation approach*

The evaluation of UCCs requires defining relevant design parameters and assessment metrics that reflect realistic processes and can be integrated into simulation models for deriving meaningful conclusions. Prior to developing the DES model, all relevant parameters must be determined. They are the inputs and generate the system diversity by being set to different values in several combinations. MTM helps to quantify the them. The outputs are performance metrics, such as lead time and throughput, as well as monetary aspects, such as investments or personnel costs.

Table I summarizes all relevant design parameters based on the literature analysis. The UCC types studied include various container sizes, swap bodies (non-stackable freight containers specifically designed for road and rail transport), and storage rooms of different sizes (the small storage room having an area of 50 m² and the large one 100 m²). The parameters include four different combinations of parcel volume and weight (A, B, C, and D), subsequently referred to as parcel flow. Each one represents a distribution of parcel weight and volume. Flows with larger or heavier parcels yield a lower number of parcels in total. Standardized parcel formats are used. Volume and weight are calculated using average values. Roll containers and Euro pallets are used as load carriers, and respective volume utilization rates are determined. Also, various handling equipment for transporting the load carriers is considered. Identification technologies, such as barcode scanners and radio-frequency identification (RFID), and different storage strategies, such as FIFO, LIFO, and chaotic are used to capture parcel information and optimize the sorting and picking efficiency.

B. *Implementation with discrete-event process simulation*

In this subsection, the method for determining the number of required load carriers and calculating the capacities of UCCs for a certain application scenario is introduced. It is also explained how floor space utilization in warehouse management is determined.

TABLE I. MORPHOLOGICAL BOX CONTAINING THE IDENTIFIED DESIGN PARAMETERS AND THEIR CHARACTERISTICS.

<table>
<tr><th>Design Parameters</th><th colspan="60">Characteristics of Design Parameters</th></tr>
<tr><td>Parcel flow</td><td colspan="15">A</td><td colspan="15">B</td><td colspan="15">C</td><td colspan="15">D</td></tr>
<tr><td>Load carrier</td><td colspan="30">Roll container</td><td colspan="30">Euro pallet</td></tr>
<tr><td>Handling equipment</td><td colspan="30">Manual operated pallet truck</td><td colspan="30">Electric pallet truck</td></tr>
<tr><td>Identification technology</td><td colspan="15">Smartphone</td><td colspan="15">ID glove</td><td colspan="15">Camera</td><td colspan="15">RFID</td></tr>
<tr><td>Storage strategy</td><td colspan="20">FIFO</td><td colspan="20">LIFO</td><td colspan="20">Chaotic</td></tr>
<tr><td>UCC type</td><td colspan="12">10 ft container</td><td colspan="12">20 ft container</td><td colspan="12">Swap body</td><td colspan="12">Small storage room</td><td colspan="12">Large storage room</td></tr>
</table>

To start, the number of required load carriers is determined based on the calculation of the load capacity of a single load carrier in terms of parcels. The load capacity depends on the assumed parcel volume in the respective use case, the internal volume of the respective load carrier, and the volume utilization rate the CEP provider is aiming for.

The internal volume V of a load carrier is determined using geometric dimensions from technical data for roll containers and Euro pallets. The load capacity C of a load carrier is calculated by multiplying V with the volume utilization rate ρ divided through the volume v of an individual parcel as

$$C = V \rho v^{-1}. \quad (1)$$

Hence, the number of load carriers can be computed as the number of parcels overall divided through the number of parcels a single load carrier can carry.

After that, suitable UCC types can be selected based on their storage capacities (see Figure 2 for an exemplary application with a 20 ft container, comparing the layout drawing and the simulation model). UCC types with storage capacities equal to or greater than the calculated number of load carriers are considered as potential solutions.

Figure 2 shows the simulation model with transport module (center), workstation module (upper left corner), and storage module (upper and lower part). The transport module consists of footpaths and workstations. The workstations define where the employee should stand during transfer or handling. The workstation module is composed of only two single stations. These are intended to simulate the process of placing the package on the table and the identification process by scanning it with a camera or RFID. Each cell of the warehouse module consists of a warehouse and two individual stations, and one cell is provided for each storage location. The warehouse allows to keep a single load carrier on it. Left and right single stations are used for depositing the load carrier during a temporary stopover and for transferring the parcels to the waiting load carrier in the UCC.

The floor space utilization rate is an important metric in warehouse management, representing the ratio of the space effectively utilized for operational purposes compared to the total warehouse area. A higher floor space utilization rate is generally desirable, but limits exist since warehouse operators and their equipment still need to move around. Floor space utilization rate is calculated using the ratio of used warehouse area and gross warehouse area.

Regarding the time analysis of the storage and retrieval, different time intervals are defined based on the sorting methods used. The total lead time is the sum of the time for storage executed by the truck driver and the time for retrieval (i.e., picking times) executed by the cargo bike rider. The process of retrieval begins with the cargo bike arriving at the UCC and ends when the last parcel assigned to the respective tour has been loaded into the bike. For all simulation runs, a medium-sized cargo bike with the loading capacity of 1.25 m^3 and a loading weight of 150 kg has been assumed.

In order to obtain a comprehensive understanding of the system behavior of a UCC, sufficient simulation results must be generated and collected. This can be accomplished by running multiple simulations. The execution of those simulation runs can be optimized using experimental design and thereby reducing the number of final runs and avoiding duplication. The simulation model, adapted to different UCC types, is created using suitable simulation software. It features an intuitive and modular user interface for easy implementation and parameter adaptability. Recorded simulation results are documented for subsequent data processing.

IV. CASE STUDY: APPLICATION IN MUNICH SCHWABING-WEST

This subsection presents an assessment approach for UCCs, discussing results and findings. A case study in Munich is used to compare different UCC types based on planning data. With the district of Schwabing-West as an example, the number of UCCs and parcel distribution are determined based on population size and delivery rates. Storage capacity and the number of carriers are taken into account to calculate the minimum number of UCCs required.

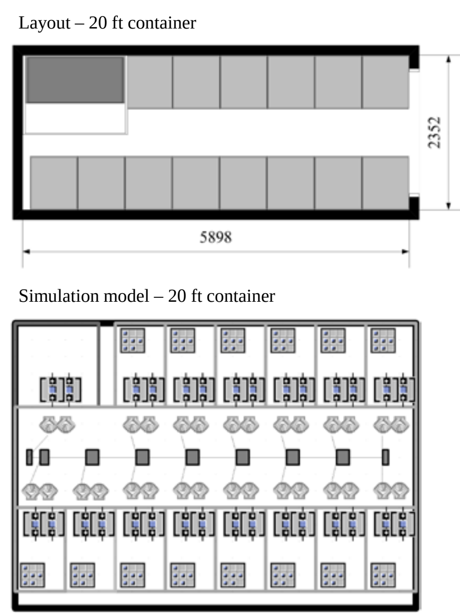

Figure 2. Comparison of the layout drawing with the simulation model of the 20 ft container.

In the example of Schwabing-West with 68204 inhabitants and an average delivery rate of 0.2 parcels per inhabitant and day, this results in a total volume of 13641 parcels per day [28][29]. There are five CEP service providers, each of which therefore has to process about 2730 parcels per day. Based on a UCC delivery radius of one kilometer, two UCC locations with a diameter of two kilometers are selected for sufficient coverage [30].

The estimated number of parcels per UCC that need to be processed on a daily basis is approximately 1,365. However, it should be noted that seasonal deviations of capacity demand can cause the necessity for a UCC to offer more storage capacities. The results presented in the following have been generated using an average over the four different parcel flow scenarios A to D and the respective simulation results. The number of UCCs in the district is kept as low as possible for as long as the capacity requirements are met.

With the assumption that only one type of UCC with the same parcel volumes exists in the planning area, a simulation model was developed to evaluate the processes within a UCC. The simulation model was generated with *Tecnomatix Plant Simulation* [31].

To vary the parameters in Table I, four test groups have been created. Test Group 1 (192 simulation runs) considered parcel flows and load carriers. In Group 2, handling devices were compared over 16 simulation runs. Group 3 was meant to compare identification technologies and storage strategies (320 runs). The scope of Group 4 with 18 simulation runs was the comparison of UCC layouts. This yields a total sum of 546 executed simulation runs.

The results were evaluated from a logistical and monetary point of view, considering setup and operational costs. In the following paragraphs, the results of this case study are presented. They are also shown in Figure 3.

At first, the choice of different load carriers is considered – see sub-figure 3(a). Throughput for storage and retrieval of roll containers and Euro pallets varies by the UCC type considered. Storage time per parcel tends to increase with a larger number of load carriers, as larger UCCs require longer transport and transit times. The cost comparison between roll containers and Euro pallets shows that Euro pallets have the lowest investment costs in most UCC type scenarios (since they are the less costly type of load carrier).

On the other hand, roll containers have lower average variable costs. Due to reduced operating times, the use of roll containers can reduce the total storage time significantly. The result is that the throughput for storage operations varies between roughly 2800 parcels per hour (p/h) for 10 ft containers and more than 9100 p/h in a large storage room when roll containers are used. The throughput that can be reached when using pallets varies between 2500 and 8400 p/h for the two respective UCC types. When it comes to retrieval, roll containers enable throughputs of 680 p/h for 10 ft containers and 370 p/h for large storage rooms, in contrast to 670 and 260 p/h for the pallets.

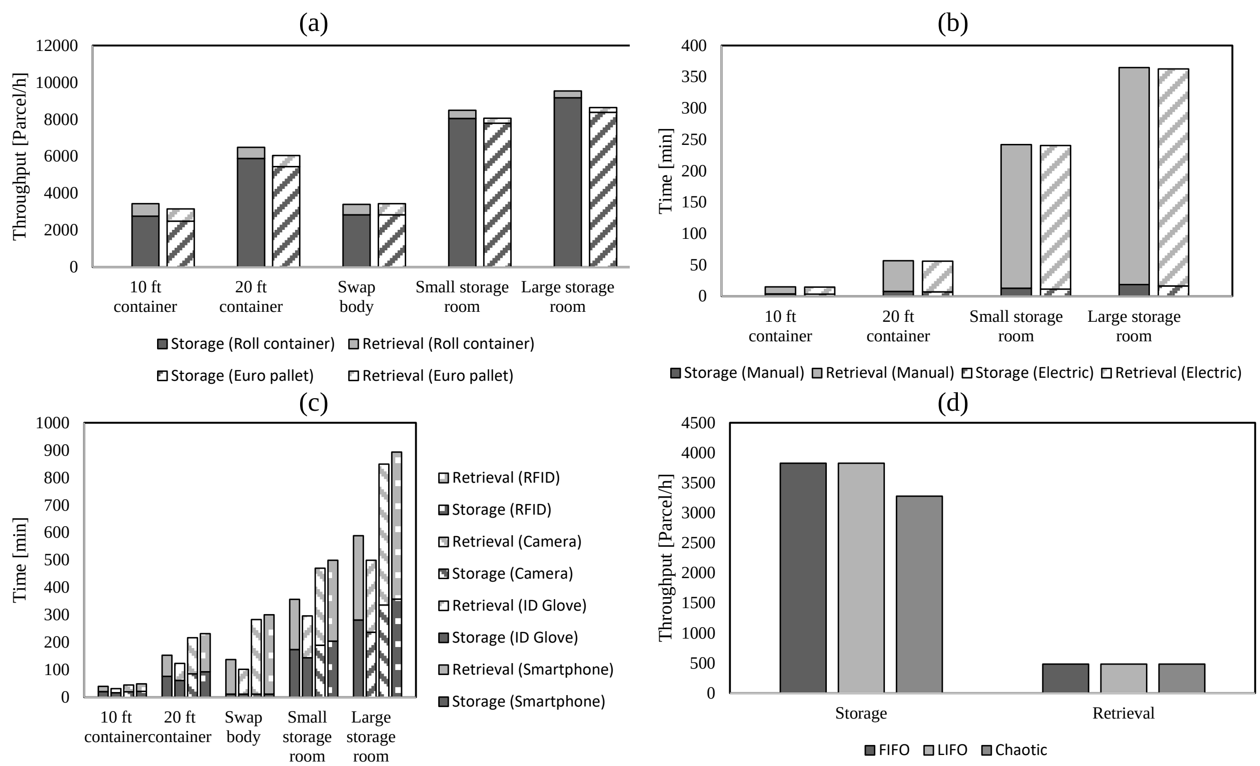

Figure 3. results of the case study simulation: (a) Throughput by storage and retrieval regarding load carriers (b) Storage and the retrieval time regarding handling devices (c) Storage and the retrieval time regarding identification technologies (d) Throughput regarding storage strategies for all UCCs.

Regarding floor space utilization, roll containers show a better utilization rate than pallets. Among the different layout types for UCCs, roll containers reach up to nine percentage points more in that metric. The reason for this can be found in the compact design. In a 20 ft container, the floor space utilization rate reaches the highest value of 38 %, whereas in the large storage room, only 12 % can be reached. This low floor space utilization is due to the layout structure of this large room which requires additional picking aisles, thereby reducing the amount of space available for storage purposes.

The next part of the case study is the examination of different handling devices – see sub-figure 3(b). Electric pallet trucks show a shorter storage time due to their better maneuverability and speed. This means that, when summing up the required lead time per parcel for storage and retrieval, electric pallet trucks can save less than one minute when a 10 ft container layout is used. However, with a large storage room, a lead time reduction of roughly 2.5 min can be observed. In relative figures, electric pallet trucks enable a lead time reduction between 0.7 % and 1.8 %. The retrieval time accounts for the largest share of the total lead time.

Hand pallet trucks, on the other hand, are more economical due to their lower purchase price. Depending on the type of UCC layout used (which means a different number of UCCs and therefore also a different number of handling devices are needed), the fixed costs can vary by a factor of 10. However, electric pallet trucks always cause about 260 % of the fixed costs of hand pallet trucks.

The next aspect covered by the case study are the different identification technologies for the parcel sorting – see sub-figure 3(c). The results show that the sorting speed of the different technologies is in descending order as follows: ID glove, smartphone, camera, and RFID scanner. The retrieval time accounts for a larger share of the total lead time compared to the storage time. The results show that the ID glove has the shortest total lead time for all UCC layout types, while stationary RFID scanning causes the longest lead time. The use of a smartphone as an identification device in parcel sorting is the most cost effective. The ID glove can reduce variable costs even more in most cases, but it is not always the most cost-effective solution overall due to its high purchase price. The use of cameras and RFID results in higher capital costs and lower storage performance.

The final subject considered in the case study is the influence of different storage strategies – see sub-figure 3(d). Regarding storage time based on the average value of all the UCCs, the chaotic storage principle achieves the largest storage time and thus the lowest efficiency due to the additional documentation the operator needs to deal with. The FIFO and LIFO principles, on the other hand, have a lower storage time and therefore a higher throughput (both reaching 17 % higher values than chaotic storage). For retrieval, the storage strategies perform similarly to each other, and the achieved throughputs vary by less than 1 %. As a result, the chaotic storage can be observed to have the highest personnel costs among the three storage strategies.

Overall, the results show that the use of roll containers, electric pallet trucks, ID glove and the LIFO storage principle are the most efficient design options.

V. Discussion

A. Research findings

In this paper, UCCs as important parts of inner-city distribution logistics were evaluated using DES and varying different design parameters. As a starting point, the relevant design parameters and different types of UCCs were determined. These parameters were then summarized according to study objectives, used for an evaluation approach, and implemented in simulation models. Those DES models were adapted for all UCC types considered.

In the planning example for Munich Schwabing-West, several scenarios for parcel quantities, sizes, and weights were assigned to various UCC types. The optimal number of UCCs to deal with these parcel volumes was then determined. Subsequently, the different UCC types were evaluated and compared using the evaluation approach and the constructed simulation model. To evaluate the different UCCs, logistical and monetary aspects were considered. The cost analysis focused only on acquisition and personnel costs but could be extended in the future to include insurance and ancillary costs, such as electricity and water.

Through the sensible use of identification and communication technologies and electric devices, logistical performance in the UCC could be significantly increased, while personnel costs could be lowered through the reduction of working time. This reduction could be reached by the increased identification efficiency in parcel sorting related to the use of reliability-enhancing identification technologies. However, due to the high purchase price, introducing technological equipment is not necessarily an absolute ideal solution for all UCC scenarios. Furthermore, it should be noted that the choice of the appropriate load carrier depends on the specific requirements of the UCC and the nature of the storage and delivery processes.

In the last part of this work, the recommendations for the design parameters of UCCs were derived regarding the simulation results and the applied evaluation criteria. The evaluation approach developed for this purpose and the designed and built simulation model were thus verified and validated on the basis of the quantitative simulation results from the practical case study in Munich Schwabing-West.

B. Limitations and future work

However, the simulation runs executed for the evaluation were reduced to only that amount which was necessary for the most relevant study objectives in order to save computational time and modeling effort. It could lead to the risk that resulting simulation results are not taking into account potential hidden interactions between certain design parameters in combination with the UCC types.

The time window per day for the employee was consequently set to eight hours. However, this working time might not be optimal for all potential use cases. Also, the warehouse process was only simulated for one UCC within one day. In the future, the simulation model could be extended to several UCCs with a longer time interval, e.g., one week, in order to provide more accurate results about the cooperation between the UCC and CEP service providers.

 ISBN: 978-1-68558-102-2

The investigation of the UCC system can be further optimized in subsequent research through test trials in real laboratories in order to gain a comprehensive overview of UCCs in various application scenarios and to ensure the most precise and comprehensive evaluation possible.

VI. CONCLUSION AND FUTURE WORK

With the use and expansion of environmentally friendly delivery transport, such as electric cargo bikes, and the high handling capacity performed in inner-city areas, UCCs become an increasingly important and conceivable solution to make the last mile delivery of CEP service more efficient. By using UCCs and working closely with cities and municipalities, logistics and traffic, problems can be mitigated to help reduce congestion and emissions in inner-city residential areas. The consideration of costs involved depending on the choice of configuration parameters helps to select an appropriately designed UCC. To this end, the use of roll containers, or (alternatively) electric pallet trucks combined with ID gloves helps in finding a balance between costs and achieved logistics performance.

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