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Drive-Thru Loading Concept for In–Plant Milk Runs

At the Institute for Materials Handling, Material Flow, Logistics of the Technische Universität München a fully automated loading system for tugger trains is currently under development. The new concept can solve the major disadvantages of available technologies such as long duration of loading tasks, and higher lead times, high manpower requirements, physical stress and an increased error rate within the milk run process. In addition to the detailed process and technical description of the concept, this paper shall give a overview on the currently available automated loading technologies following a comparison and benmchmark between the concepts.

Keywords: *Tugger train, Milk run, Material supply, automated loading, Automated Storage and Retrieval System*

1. INTRODUCTION

The provision of materials for production areas is becoming increasingly demanding. A motivator for this trend is especially the more frequent production of different products on the same industrial facilities and the thus following higher number of different materials which must be supplied in production. The compression of material necessary for this can only be achieved with smaller load carriers which are supplied in high frequency. The trend towards smaller load carriers is also enforced by the desire to lower stocks in production. [1 pp.32]

To attain these goals and nevertheless guarantee the security of supply of production, a synchronisation between production and logistics is necessary. [2,1 pp.275] The supply of replenishments for production stands in conflict of goals between strategies which are resource-poor and thus affordable, and a security-oriented and flexible interpretation of the supply processes. A possibility to counteract this conflict of goals is the use of tugger trains (in-plant milk runs, routine trip) for the supply of material. This trend is catching on increasingly, especially in the automotive industry. [3,1 pp.275]

In practice mostly manually operated trucks with several trailers are used as tugger trains. The driver of the tugger train supplies the material in production and takes emptied load carriers with him at the same time. Highly diverse load carriers can be transported with tugger trains, in the further progress of the article only concepts for the provision of small load carriers (SLC) shall be observed.

The starting point for the provision is a warehouse close to the production site or a supermarkt (SuMa) from which the required material is taken and loaded onto the tugger train. On its route the train transports the material to the places of need in production. There, the driver of the tugger train supplies the full load carriers and takes emptied load carriers with him. At the end of the tour, the tugger train transports the collected empties to an empties buffer and starts the new tour beginning with the loading process at a predetermined point in time.

The location of the warehouse and the conditions in production decisively determine the transport path and the effort for the supply of material. There is significantly more organizational flexibility when loading the tugger trains. There are concepts in which the tugger train driver loads the trailers in the warehouse or supermarket by himself (figure 1a). In other applications, a further logistics employee loads the trailers and the driver of the tugger train exchanges the entire train or the trailers in a transfer area (figure 1b). In some companies the tugger trains are loaded automatically in which case the tugger train is not loaded directly but transport racks are taken from the trailers and are supplied to the automatic loading by materials handling technology (figure 1c).

A new approach being developed and tested by the Institute for Materials Handling, Material Flow and Logistics of the TU Munich is depicted in digram 1d. In this case a drive-thru concept is used, in which the tugger train stops at a loading station and is loaded there automatically.

The advantage of an automised loading is the possibility of almost entirely neutralising physical stress in this process. A second significant advantage is the prevention of mistakes during loading. In manually operated warehouses there is the possibility that the employee takes the wrong material. Such mistakes are mostly only realised at the place of demand and must be alleviated with a lot of effort. Also in the supply of material mistakes can be reduced if the driver of the tugger train is supported in the material supply. For the employee it is simplest to take the material in a determined order. Corresponding with the order of supply the material is arranged on the tugger train. The employee must only take the material in the defined order and supply it corresponding to the information on the SLC. This way the search effort when taking the material and the possibility of mistakes is almost eliminated.

The creation of a specific order of SLC is very elaborate in manual systems and not practicable due to the high steering effort. In automised systems this order can be created by materials handling technology.

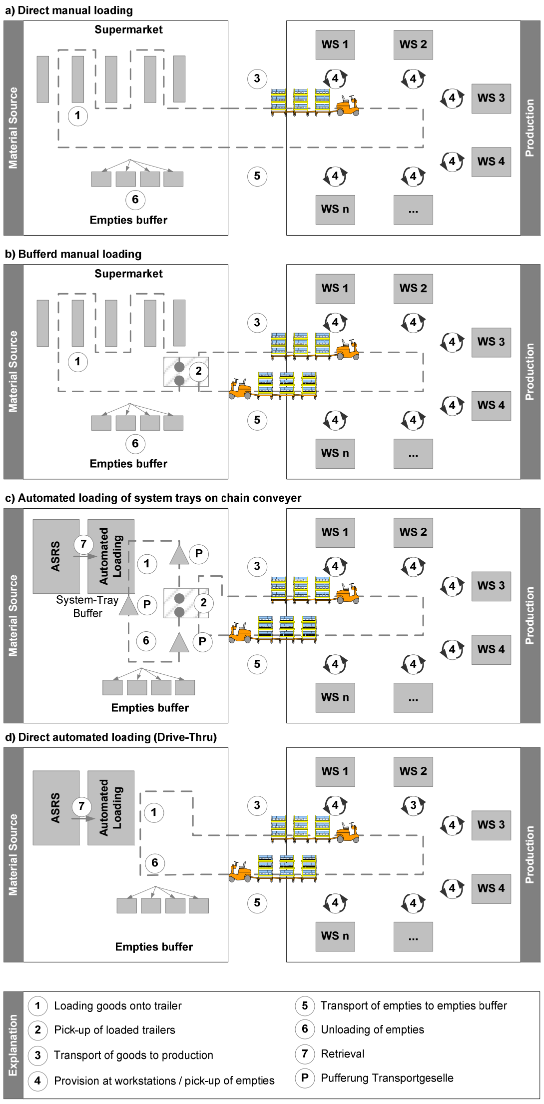

Fig. 1: Different concepts for the supply of SLC tugger trains

2. AUTOMISED LOADING OF TUGGER TRAINS

There are three basic approaches how the order (sequence) can be created. In the simplest case the material is taken out of store based on the route and an employee creates the sequence manually. However, this approach creates further sources of mistakes. The second approach is based on the idea of already creating the sequence in the automated storage and retrieval system (ASRS) with the stacker cranes (STC). This leads to interactions between the different warehouse gangways which cannot be kept busy. Correspondingly, the SLC must be arranged for a higher performance. If the finding of material in the warehouse is inhibited due to many fringe conditions, this concept can no longer fulfill the task. The approach used most frequently is the sorting of SLCs in the ASRS prezone. This can be done by different sorting levels with conveyor technology for example, or through an additional level of handling with storage and taking out of storage in a highly dynamic buffer. This approach frequently leads to very high investments and elongates the time necessary for taking out of stock and supply. Due to this the „ordering service“ for a tour must be completed earlier, which leads to an increase of the replacement time. The replacement time is defined as the maximum time between the retrieval of material and a supply for production. [4, pp.203] A lower replacement time enables the reduction of stocks in production without decreasing the supply tact.

3. CONCEPT

A new concept which was developed at the Institute for Materials Handling, Material Flow and Logistics (fml) of the Technische Universität München and analysed in a simulation study can reduce the technical effort in the prezone of the warehouse without decreasing the performance of the STCs. The concept intends an automised loading of the tugger trains adhering to sequence. Significant components of the automatic loading of tugger trains are an ASRS for the stocking of material as well as materials handling technology which leads the SLCs from the warehouse to a loading station. The loading station itself is made up of loading shelves and a technical appliance (e.g. small stacker cranes or hubben-stacker cranes) which sorts the SLCs into the loading shelves. With these loading shelves the SLCs are loaded into the transport racks on the tugger train. Both the loading shelf and the transport frame are flow racks.

The SLCs are taken out of stock from the small parts store, transported over the conveyors to the loading stations sorted directly into the loading shelves without intermediate storage (see figure 2). Through this new concept the last order service can be set temporally very close to the taking out of stock and thus a fast supply is enabled.

Fig. 2: Loading station for the automatic loading of tugger trains

At a defined point in time t_1 (see figure 3) right before the beginning of the unloading from the small parts store, the loading order for the transport racks on a tour is calculated using the existing retrieval orders. This is based on the driving route of the tugger train so that the driver of the tugger train has a determined order of removal and his search effort is minimized. The control checks the loading order and determines the exact target place (transport rack, shaft, position in the shaft). If this IT process is completed, the warehouse management system assigns the unloading orders to the SLCs. In this case the typical unloading strategies can be used which intend that all warehouse aisles are working to capacity. Then the small parts store conducts the cleared unloadings. With a slight temporal delay due to the delivery time of stacker cranes and supply of the storage prechamber, the first SLCs arrives at the transfer point of the loading stations. These facilities arrange the SLCs in the predetermined shaft of the loading shelf. If all containers are loaded into the loading shelf, the loading of the transport racks on the tugger train can happen. For an improved decoupling between the supply and loading, the capacity of the loading shelves can be doubled. This has the advantage that in the case of possible irregularities in the tugger train timetable the supply of the next tour can be conducted independently.

The performance of small parts stores and loading stations are coordinated with one another. As the loading stations sort into every shaft but cannot change the order of containers within a shaft, this must already be guaranteed by the unloading of the small parts store. That is why all small parts stores, which have the same position in the shaft as a place of destination, are combined in one retrieval wave. The different retrieval waves are then cleared for unloading to the small parts store (see figure 2). As per wave there is a maximum of one small parts store for every shaft, the loading station can reliably create the sequence. Within one wave there are therefore no requirements of sequence for the small parts store. A possible strategy to prevent the mixing of SLCs within a shaft is to clear the single retrieval waves strictly one after the other. For this all SLCs of the last waves must have passed the control point (c-point) of the warehouse before the next wave is cleared.

Due to this there are waiting times for the single stacker cranes during the transition to the next retrieval wave. The waiting times result from the different number of SLCs to be unloaded per warehouse gangway, differently long stracker crane running times and the supply time to the c-point.

In another strategy the retrieval waves are additionally combined with each other. As soon as an SLC of the previous retrieval wave has passed the c-point, the next container in the corresponding shaft from the next wave is cleared. Thus the number of SLCs ready for retrieval at the same time is kept more stable than with the first strategy and waiting times for the stacker cranes are reduced.

However a problem with both strategies is the high number of SLCs which come to the loading stations in short time and must be temporarily buffered during the conveyed way. The maximum security of supply of the loading stations is thus contrasted with high investments of conveying technology and a lowered performance of the small parts store.

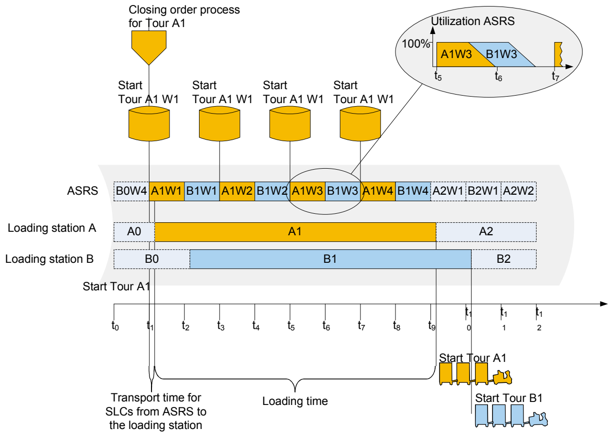

Fig. 3: Interaction of the information technology, the autmatic small parts store and loading station for the sequenced loading of tugger trains

To prevent this disadvantage and keep the waiting times of the stacker cranes as low as possible, it is sensible to mix the retrieval waves of different loading stations. Wave 1 for the loading station A then follows wave 1 for loading station B (see figure 3). Up to the starting point of the unloading of wave 2, all containers have thus surely passed the c-point. The mixing of waves also enables the temporal distribution of the arrival time of the retrieval waves over the loading time of a loading station. Therefore there are less stacking places on the conveyance technology intended for the single stations. The steering must however observe that the last wave of an order is cleared in time, so that all SLCs are unloaded, transported over the conveyor and can be sorted into the shafts on the loading station.

4. CHALLENGES IN THE TRANSFER OF THE SLC TO THE TUGGER TRAIN

As mentioned before, to make the process of feeding the loading shelves independent from the milk run process the loading shelves can hold two complete batches. To separate the SLCs of both batches, the small stacker crane automatically releases the first depth (collection depth) and the batch glides into the second depth (transfer depth). The transfer of SLCs from the collection depth to the transfer depth and the transfer into the transport racks are the critical interfaces. In respect of a cost effective and lean processing solution no power driven equipment or sensor systems were used. Within the loading shelves the SLCs glide gravity-driven on inclined planes. Due to this passive solution possible error sources are created which in operational use cannot be detected or resolved automatically.

One possible undetected error occurs in the case of SLCs getting stuck in the collection depth. This leads to a mixing of SLCs of different tours which, in the worst case, is unnoticed until the tugger train driver delivers the goods. This error source must be eliminated by suitable constructive measures. The prototype tests have shown that especially the tilt angel, roll type, the SLC weight and the type and positioning of goods inside the SLC influence the rolling characteristics. A high tilt angle of the flow racks has a positive effect on the process stability but is restricted by the translational momentum when the SLC collide with stop bar (fragile goods could be damaged or bulk goods could fall out of the SLC). Therefore, special brake rollers with a acceleration dependent breaking effect are used to slow down the SLC smoothly.

Possible error sources while transferring the SLCs from the loading shelves into the transport racks are tipping of SLCs in the transfer-gap or getting stuck in the transport rack. First of all, an exact positioning of the transport racks in front of the loadings shelves is necessary. Therefore, several factors must be considered (see Table 1).

Table 1: Influencing factors on the relative position of the transport racks

Influencing factor	Impact on		
	x	y	z
Manufacturing tolerance of tranport racks	o	o	o
Manufacturing tolerance of loading shelves	o	o	o
Clearance in trailer couplings	o		
Positioning tolerance of transport racks on trailers	+	+	
Positioning tolerance of tugger train	+	+	
Directional stability of trailers		+	
Bowing of flow planes under load			o
Abrasion		o	o

Explanation
x Direction of travel axis
y Lateral direction axis
z Height direction axis
+ Strong impact
o Medium impact

To make the positioning in the direction of travel (x-axis) easier, several constructive measures were applied. Crosswise, the shafts of the loading shelves are wider than the shafts of the transport racks. Due to this the position tolerance is enhanced if the SLCs are placed centric in the shafts of the loading shelves. The trailer couplings are without clearance and the transport racks are positioned on the trailers using centering devices. The positioning of the tugger train itself is done manually by the driver. Therefore, a laser pointer is mounted on the housing of the truck to project a position mark. Combined with markings on the floor the driver can see the ideal driveway and breakpoint.

For a correct transfer of goods the transfer gap in which SLCs are not supported by rolls (lateral direction, y-axis) must be minimized. To eliminate the influence of the directional stability of the trailers and the inaccuracy of a manual positioning the trailers are restraint-guided by rolls mounted to the housing and a separate guide rail.

The prototype tests have shown that offsets in height direction are critical, especially when the flow planes of the transport racks are higher as the loadings shelves. Even small offsets lead to an interfering edge. As a general tendency the planes of the flow racks should be mounted slightly lower than the ones of the loading shelves to prevent influences by the unevenness of the floor or dirty wheels.

Last but not least, the selection of rolls in the transport racks is very important. The use of roller tracks simmilar to those in the loading shelves, which grant the best rolling characterisics, is not possible. Due to acceleration an vibrations the SLCs would damage the roller tracks. On the other hand, full-width rollers differ considerably in starting torque and rolling characteristics. Manufacturing tolerances (imbalance) and the quality of ball bearings must receive special attention.

If, despite all constructive meassures, a SLC is not transferred into the loading shelve correctly, this error must be resolved by the tugger train driver manually. Therefore, a solution was chosen in which the driver has to release every loading shelve manually so he can see possible errors directly in contrast to the automatic release of the collection depth.

5. COMPARISON OF CONCEPTS FOR AUTOMISED LOADING

Due to the absence of buffering steps for loaded transport racks the drive-thru concept is substantially different to other automated loading concepts. Within the other concepts transport racks are taken off the trailers and transported to the loading stations either manually (concept 1) or on conveyor technology (concept 2). Figure 4 shows the therefore required handling steps for all three concepts.

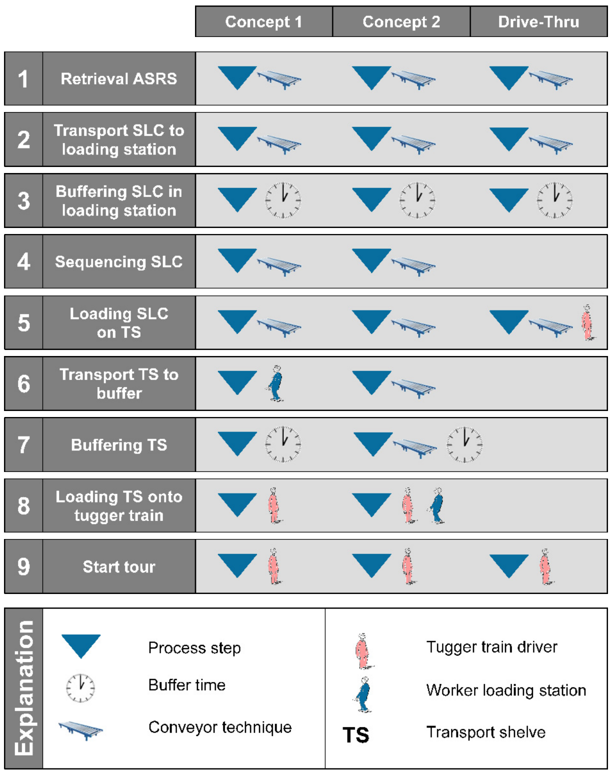

Fig. 4: Comparison of required process steps for different automated loading concepts

Within all three concepts, the loading process starts with the retrieval in the ASRS, the transport of the SLCs to the loading stations via conveyor technique. Within concept 1 and 2 the SLCs are picked by the small automated stacker crane and buffered in separate racks or, within concept 3, buffered inside the loading shelves. Since the automated stacker crane can start working when the first SLC arrives at the loading station steps 1-3 can partly be done at the same time.

The fact that the SLCs are fed into the loading shelves in the correct sequence is a major difference of the drive-thru concept in contrast to the other two concepts in which the SLCs must be handled twice. Furthermore, the transport racks are never taken off the tugger train and now additional employees or technical equipment are required.

The duration of all process steps starting with the retrieval in the ASRS until the SLCs / transport racks are completely loaded onto the tugger train can be described as technical lead time (see figure 5).

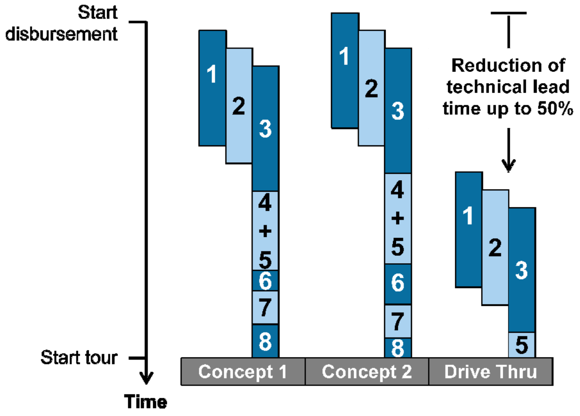

Fig. 5: Comparison of technical lead time for different automated loading concepts

6. BENCHMARK OF THE DRIVE-THRU CONCEPT

In addition to the benefits mentioned in chapter 5, the drive-thru concept grants several advantages. To evaluate those, a benchmark between the different concepts was part of the development. Based on a predetermined scenario different aspects were rated, such as:

- required investment and floor space
- time for automated loading tasks using cycle-time calculations
- time for manual loading-tasks using methods-time measurement
- ergonomics
- process stability

Since now equipment for SLC sequencing or transport shelve handling is required, the investment is reduced and less floor space is required. Also, since SLCs are handled by the rack feeder only once, less time is needed for automated and manual loading tasks. This leads to an almost doubled capacity per loading station.

In concept 1 and 2 an additional employee is required either to feed the transport racks to the loading stations or a fork lifter driver to take off the transport racks. Within the drive-thru concept, only the tugger train driver fulfills loading tasks. As a consequence, less manpower is required to load a tugger train and the automation level is higher. Since the tugger train driver only releases the loading shelves and checks the correct SLC transfer, no additional physical stress is created due to the loading process (especially in comparison to manual loading concepts).

In contrast to positives which can be found in the quantitative performance data some negatives can be seen in the decoupling between ASRS and tugger trains and the tugger trains themselves.

The absence of re-sequencing steps for SLCs causes a tighter coupling between the loading process and the ASRS. As described in chapter 3, the ASRS must assure that the different retrieval waves are not mixed while within concept 1 and 2 the final sequence can be established by the loading station itself.

Unlike in concept 1, where transport racks can be taken out of the buffer and loaded onto the tugger trains in a free order, the required order of arrival is fixed when the first SLC is loaded into the loading shelve. If a tugger train arrives not in time, the next train, which shall be loaded in the same loading station, must wait until the transfer depth is cleared, causing a tighter coupling between the different tugger trains. The detailed results of the benchmark can be found in table 2.

Table 2: Benchmark results of automated loading concepts

	Concept 1	Concept 2	Drive-Thru
Investment [€]	204.000	300.000	96.000
Required floor space [m²]	55	108	48
Transport shelve loading time [min/tour]	17,7	19,9	10
Output [tours/h]	3,4	3	6
tugger train loading time [min]	0,5	2,8	1
Tachnical lead time	- -	- -	o
Required manpower [employees/tour]	0,22	0,28	0,1
Ergonomics	+	+ +	+ +
Decoupling between loading and ASRS	+	+	o
Decoupling between tugger trains	+ +	-	-

Improvement
Unchanged
Decline

7. CONCLUSIONS FOR THE REPLACEMENT TIME

From a customer point of view, the maximum time between the stock falls below reorder level and time of replenishment which can be assured by the supplier is of special interest. On basis of the replacement time the required stocks at the workplaces and reorder levels are defined. Depending on the logistics concept different time shares must be taken into account. Figure 6 shows this correlation using the example of a kanban-card-system.

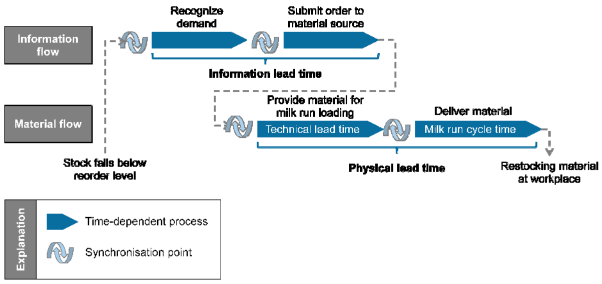

Fig. 6: Time shares of replacement time in milk run supplied systems

By the time the stock falls below the reorder level this event must first be recognized (synchronization between reorder process and material consumer). Next, the order must be submitted to the material source. Due to the submission (e.g. transport of kanban-cards) and synchronization effects (e.g. collecting kanban-cards before submission) dead times can occur [1, pp.180]. The therefore required time shall be described as information lead time. In some logistics concepts an information lead time does not apply. If, for example, the determination of demand is calculated by bill of materials explosion (demand-driven) demands are recognized automatically without delay.

Usually, an order which reaches the material source is not transformed into a stock-removal order instantly but has to be synchronized with the loading and delivery process of the tugger trains. To achieve a high transport load, orders are collected within the warehouse management system causing an additional dead time.

When a predefined time prior to the start of the tour is reached all orders are transformed into stock-removal orders (see chapter 3) and the retrieval starts. Next, the technical lead time is required to load the SLCs onto the tugger train. Finally, the driver needs some time to deliver the material to the workplaces.

As part of the replacement time, a shorter technical lead time lowers the replacement time by the same amount. Orders for a specific tour can longer be accepted. From the opposite perspective, this means that the recognition of demand can be closer to the start of a specific tugger train tour which leads to lower reorder levels and material stocks at the workplaces.

8. SUMMARY

In times of increasing numbers of variants that are produced on the same production facilities, logistics processes are becoming more and more complex. The aim of providing a higher number of different goods at the workplaces can only be achieved by using smaller load carriers which must be stored and handled within intralogistics processes. Therefore, a compression of materials during transport and a highly frequent material supply is necessary.

Establishing in-plant milk run concepts or tugger trains is an efficient way to supply the production areas at much higher frequencies while, at the same time, traffic and accident risk are reduced. [1, pp.184] While the requirements for planning and controlling milk runs are mainly set by the manufacturing areas and the plant layout, the loading process can be designed more freely.

Despite the fact that in-plant fully automated storage systems are becoming more and more a standard solution in the automotive sector, the automation level of loading milk runs is falling. This leads to high manpower requirements, physical stress and an increased error rate within the milk run process.

The new Drive-Thru concept allows the integration of milk run loading tasks in fully automated material flow systems. Due to the central location at the output points of the ASRS the concept can be a cost-effective solution. In comparison to other automated loading concepts in which transport racks are taken off the tugger trains, the drive-thru concept grants several advantages. Since trailers are not buffered after loading, the lead time for preparing a tour is reduced and less floor space is required. Furthermore, all direct loading tasks are fully automated. The driver only fulfills control activities which reduces his physical stress caused by loading activities.

Because handling steps and the required loading time are reduced, ordered Material reaches the production areas quicker. Stocks can be reduced without increasing the supply frequency.

In close cooperation with an industry partner, a prototype of the system is currently tested at the Institute for Materials Handling, Material Flow, Logistics. The initial operation at a plant of an automotive supplier is expected to be in July 2013.

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