Future of Material Handling – modular, flexible and efficient

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Abstract – This article discusses the limiting factors for material handling systems and the consequences. We also present some guidelines for the design of future generations of material handling systems which allow to overcome these limitations. As an example two new systems, which have been consistently developed to fulfil these guidelines, are introduced.

I. INTRODUCTION

The demands on material handling systems are changing. Rather than level of automation, cost effectiveness and maximum throughput, other characteristics are more important today: flexibility, reconfigurability and high availability. In every manufacturing business the diversity of products is dramatically increasing. The introduction of hybrid engines in the automobile industry alone doubled the range of products in some of the companies, for example.

Due to virtual development, the time needed to introduce a new model in the market has been shortened rapidly, also shortening the product life cycle itself. These shortened planning horizons and smaller amortization periods result in smaller investments. The customer request for more individual products leads to mass customization, which leads to smaller quantities in almost every sector of the consumer market.

If one looks at different press reports during the economic crisis, one can clearly see a demand for flexibility. At the end of 2009 it was reported that the situation for the component suppliers in the car sector is getting worse (München, dpa-AFX). In the beginning of 2010 you could read: Car production in Germany further decreasing (Frankfurt/Main, ddp), whereas in the middle of the year it was reported, that the global car production will reach the same level as before the crisis (Frankfurt, dpa-AFX).

For most systems it was common to run for many years in the same configuration, whereas now it is often needed to change the layout and readjust it to new requirements after a couple of years - sometimes even faster. Although the industry has implemented hundreds of successful automated material handling systems in the past, there are signs that business is or will be getting more difficult. For instance, a survey in Germany showed that users of automated material handling systems have reduced their investments in automated systems or are planning to “de-automate” significantly, since the systems are too inflexible in relation to perceived changes in the requirements and processes [1]. Although this study is now somewhat dated, we believe its underlying message is still valid.

Fig. 1: “Reduction in automation in several production areas, according to ISI” [1]. Statistics indicate the percentage of respondents who were planning or who had already implemented a reduction in automation.

According to Furmans, Schoenung and Gue [2] the inflexibility is due to the fact that an adaptation of automated systems is very costly and risky. The reason for this is, among other things, that the functionality needed to provide the logistical services is spread over various levels and disciplines. The total function of such a system is also provided by interacting software and hardware, which are themselves spread out over many different levels and layers. An automatic adjustment of the structure to new tasks and load models, or at least an easy adaptability, is not intended with these systems. With a change in the procedures today, all these levels are typically modified by
several different experts.

To cope with the fast changing demands of the markets, new material handling systems need to be more flexible and alterable. An approach, that allows to reconfigure the system “on the fly”, without the loss of operational readiness, costly start-up periods and tests, is the only economical solution. Scalability in size, throughput and in the nature of the transported goods is therefore essential, in order to efficiently adapt to changing performance requirements. Ultimately, the setup, adoption and usage must be so simple that new automated systems can compete in flexibility and reusability with non automated systems. In order to achieve this goal, such systems must have characteristics similar to those in modern computing systems. Installation time and complexity has to be reduced dramatically, in order to be cost efficient [2]. Material handling systems should be set up as a plug and play solution. Once the system is physically configured, everything is done. Components can be added by simple insertion. To operate resource efficient, the system needs to be economical (therefore the ratio of weight and load needs to be better, transportation routes need to be shorter and unnecessary work needs to be eliminated). Through easy reusability of the system fewer resources for manufacturing the equipment are used [3]. To meet these demands it is advisable to build the system with small scale units, which can be combined in a very variable manner to form a complete system. This way it would be possible to react flexibly on different demands in throughput and layout. Equipped with a decentralized control, the number of participating units in a system could be easily changed without the need for reprogramming.

II. KARIS – AN INNOVATIVE SYSTEM WHICH CAN MEET THE NEW DEMANDS

KARIS (a German acronym for Kleinskaliges Autonomes Redundantes IntralogistikSystem which can be translated as small scale, autonomous, redundant material handling system) represents a realization of such a standardized, scalable, decentralized, reusable and resource efficient material handling system. The system consists of identical basic elements which are interacting and cooperating with each other to form a flexible unit. A basic element is modularly constructed, and can therefore be adapted to different specifications. It is organized in three layers, of which the lower one includes the holonomic drive unit in order to give a maximum movability. The element is able to reach speeds up to 2m/s and transport loads up to 100kg (250kg are planned). The middle layer contains the safety relevant sensors and provides space for a lifting unit, allowing the element to adapt its height to dock on different levels of the peripheral installations or to raise the work piece directly to working height. The top layer of the element is fitted with a multidirectional conveying unit, for a wide range of applications.

A. Set-up

A special feature of KARIS is the free navigation, which is not relying on a dedicated infrastructure for navigation. An arrangement of landmarks such as radio transmitter, reflectors, magnets, floor markings or RFID-tags, is not needed. The corners and faces which are present in every environment, such as walls, columns or machinery and equipment, are used to navigate. For startup, an initial map is captured with the integrated laser scanners while controlling the device manually. This raw version then is enriched with additional information of the systems environment. Examples are footpaths, restricted or hazardous areas. Other information can be provided as well. Connection points to existing conveying installations, such as an automated storage and retrieval system or other areas, are defined as transfer points and therefore serve as interfaces for the material flow. If the material flow needs to be changed, due to new models for example, transfer points can be changed flexibly to meet the new demands. It is only necessary to transmit their new coordinates, which can be done during normal operation. The decentralized approach allows to add and to remove elements from the system and therefore adapting the actual throughput. Since the path planning and the coordination among each other is done by the elements themselves, there is no time-consuming reprogramming of the system. This enables the operator to use more elements in high-times to cushion the peaks in the needed performance.

B. Cost efficient

The standardized module structure of a basic element allows the compensation of the breakdown of single units, by just replacing it with a working one. This ensures the redundancy for the system. Building costs of the elements can be reduced by the high quantities of standardized
elements, since no customizations are needed. The fact that the availability of the system is part of the system structure allows to have a lower availability for the single elements, which will reduce the building costs further compared to today’s AGVs.

C. Application fields

The application opportunities for these new Material handling systems like KARIS are promising. Not only is it possible to replace existing systems, it is also possible to find new areas of use for automated systems. A standard task is the transport of different cases one by one without having to install a cost intensive material flow system. This way it is possible to bring automation to fast changing productions and to smaller companies, which would normally rely on manual labor. Since it is possible to share routes with workers, no extra space for conveyors or streets for forklifts are needed. The material can be brought directly to the workstation, or the KARIS-element itself can serve as a flexible workstation.

In a picking area the standard procedure today is, that a worker has to push a cart, stacked with handhelds, printers or other electronic equipment, boxes and the orders which can easily sum up to over 100kg per cart. If a pick & pack strategy is used, the KARIS-element can travel alongside the worker, providing him with all the needed information, the order can be picked directly into the shipping box on the element and as soon as the order is complete it is directly transferred to shipping. Bigger orders can be processed by using more than one element providing the worker with more shipping boxes. Since the worker does not have to bring the boxes to a drop off point and new elements provide the workers with the needed boxes, a lot of time of walking around can be saved. Another strategy is that the elements maneuver freely to the picking point in the area and the workers can travel on fixed routes to serve the waiting elements. In both cases the work load for the person is drastically lightened, which is an important factor since the average age of the workforce is increasing worldwide.

III. GRIDFLOW: AN APPLICATION FOR HIGH-DENSITY STORAGE SYSTEMS

In the last years, new shuttle based systems pushed into the market to bring flexibility and energy efficiency to storage systems. Even though these systems are developing in the right direction, they do not pose a real flexible and cost efficient alternative to the existing systems, since the costs for the high rise racks are still high and it is difficult to change the layout. Often, to keep pace with the fast changing requirements, the best way is to rent a storage building as it is needed. In these cases it is not possible to install an expensive storage solution. Flexible systems with very little installations are needed that can also be dismantled when the facility is no longer in use. For many companies, therefore, the only option is to buy or rent a forklift and store the pallets on the factory floor in block storages. These storages for pallets do not contain aisles and therefore offer a very high density which makes them surface and cost efficient. The access is however limited to loading units at the edges. To retrieve a pallet from within the block several others have to be picked up, moved away, buffered elsewhere and restored after the retrieval of the desired pallet.

A. Idea of the GridFlow system

To avoid this limited access Gue and Kim [4] propose puzzle-based storage systems. These automated storage systems base on the 15-slide puzzle (see Fig. 3) and consist of a grid of loading units and conveyors with at least one empty location. Each location is equipped with a conveyor and thus each pallet can be moved to all 4 directions in the horizontal level at any time, if the neighboring location is empty. Taylor and Gue analyzed the retrieval behavior of puzzle based storage systems [5], [6]. Gue and Furmans showed that such a system can also be operated by a decentralized control [7].

![Fig. 3: “15-puzzle” [4]](image)

Due to the conveyors the system flexibility to layout changes is limited and requires a big investment. We therefore present the concept GridFlow replacing the conveyors with robots (automated guided vehicles) (see Fig. 4).

![Fig. 4: “GridFlow system with pallets and robots”](image)

Alfieri et al. [8] propose a similar system for racks moved by automated guided vehicles.

The robots make the GridFlow system very flexible to layout and throughput changes. Furthermore the system does need very little infrastructure and is easy to put into operation.

A system with one open location (escort) and one robot
offers the highest possible density \( \frac{n-1}{n} \), where \( n \) is the number of location. By increasing the number of escorts and robots, retrieval times of the system can be decreased while the density decreases as well. Thus the system can be adjusted to the required throughput while ensuring the highest possible density for this case.

To determine the number of escorts and robots for a certain throughput, we need to calculate the retrieval times depending on the number of open locations, the number of robots, the layout of the grid and the position of the Input-Output-Points (I/O-Points).

We will here consider a system with one escort, one robot and one I/O-Point.

B. Modeling the system

The model consists of a grid which is \( n \) locations wide and \( m \) locations long and holds a total capacity of \( C = n \times m \) locations. Each location can hold one loading unit. A location within the grid is identified by two coordinates, were the first coordinate stands for the horizontal axis and the second one for the vertical axis. Both axes start in the lower left corner with position \((1, 1)\) (see Fig. 5).

The position of the retrieval unit e.g. the loading unit to be retrieved is given by \((i, j)\) and that of the I/O point by \((k, k)\).

![Fig. 5: “Model of the GridFlow system”](image)

C. Basic movements

All movements considered here start and end with the vehicle being in the escort.

3-move: A 3-move swaps the position of the escort with the position of an adjacent loading unit (see Fig. 6).

![Fig. 6: “3-move”](image)

9-move: Gue and Kim [4] describe a move to transport a loading unit to a location diagonal to the escort. This move will therefore always be done at a right angle to the move before. This move takes three movements for the system described by Gue and Kim with conveyors. In a system with one robot it requires nine robot movements and is thus called a 9-move (see Fig. 7).

![Fig. 7: “9-move”](image)

15-move: The 5-move described by [4] to move a loading unit by one location in a direction opposite to the location of the escort becomes a 15-move in this system. In the beginning of this move the escort and the target location are on different sides of the retrieval unit. Therefore the 15-move will be done in the same direction as the preceding move (see Fig. 8).

![Fig. 8: “15-move”](image)

D. Retrieval process

As a robot will always end a retrieval in the I/O-Point location, and the escort will move with the robot we assume the next retrieval to start with the escort and the robot being in the I/O-Point location.

In the first phase the escort has to be moved from the I/O-Point to the retrieval unit. The target position of the escort depends on the arrangement of retrieval unit and I/O point within the grid as the number of 9-moves to be performed in phase 2 is maximized (see [4]). The number of 9-moves is maximized as with those moves the retrieval unit can be moved with less robot movements than with 15 moves.

The second phase starts with a 3-move of the retrieval unit by one location. Next the vehicle will perform as many 9-moves as possible and then clear the remaining distance with 15-moves. According to this we developed the algorithm for the optimal retrieval time as follows:

**Algorithm for retrieval of one loading unit with one robot and one escort:**

\((i', j')\): position of the retrieval unit after the last step
The analysis of the aspect ratio is aggravated by the fact that for every grid capacity there is only a discrete number of possible aspect ratios. Therefore we are not able to compare every aspect ratio for every grid capacity.

However, data from grid capacities smaller than 2000 loading units suggest that an aspect ratio of 2:1 results in the lowest expected retrieval time. For a given capacity, we therefore recommend to use an aspect ratio that is as close to 2:1 as possible.

There are grid capacities which result in very high aspect ratio and in prime number cases in a one-dimensional layout. Those extreme cases can easily be avoided in industry application.

We derived the minimum expected travel time for each
capacity smaller than 2000 and analyzed the behavior of the expected retrieval time in dependence of the grid capacity. The expected retrieval time of applicable cases tends to form a linear function for capacities bigger than 500 loading units (see Fig. 10).

As we are only able to derive the best location of the I/O-Point and the best aspect ratio from experiments, we can not give design rules but design guidelines. Those have to be validated by a mathematical optimization of the expected retrieval time which will be part of our further research.

The GridFlow system might open up opportunities in different fields of material handling providing the possibility for fast and easy setups and reconfigurations. The sorting and buffering process in cross docking centers might be an example. Robots could transport the loading units to buffering stages or directly to the outgoing ramp giving the opportunity to automate a process which is today done manually due to the needed flexibility.

Further research needs to work on different application scenarios and their evaluation. Especially strategies for the cooperation of multiple robots need to be developed and quantified.

IV. CONCLUSION

Ever faster changing requirements put today’s material handling systems to their limit. The research community agrees on guidelines for new material handling systems. New approaches have to be decentralized, modular and scalable to offer the needed flexibility.

To preserve the competitiveness of our industry we need these new systems as well as efficient strategies to use them. The presented systems KARIS and GridFlow are two systems designed according to the mentioned rules and can work as good examples for future material handling systems. With these approaches new installations do not need to be oversized from the beginning. They could grow according to the company’s growth. The evolution of new systems has just begun and there are various opportunities research can adopt and continue.

However, we have to make sure that the developed systems are economically interesting. To decide on this, it is possible to calculate monetary criteria such as investment costs, personal costs or surface costs. Especially in comparison with today’s system, the aspect of flexibility is very important but hardly measurable. This is why we need to define how much this flexibility is worth to us and the research community should think about ways to measure it.

REFERENCES