REDUNDANCY IN WAREHOUSES: TECHNICAL CONSTRUCTIONS, OPERATION STRATEGIES AND THEIR IMPACT ON THROUGHPUT

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ABSTRACT
The increased division of labor and the rising integration of globalized supply networks led to a backlash from the zero-inventory company to an upswing in the demand of warehouses. Simultaneously, there is no acceptance of delayed deliveries. Companies employed in global supply networks thus have a growing demand for warehouse capacity on the one hand side and high availability of the goods stored therein on the other. Furthermore, the warehouses must be operated with highest efficiency to minimize the effect on the company's revenues.

All these demands often lead to the planning and operation of high-bay warehouses with automated storage and retrieval systems, short AS/RS. In these systems the high bay concept leads to high capacities per floor space and the AS/RS offers low operation costs. A problem that often occurs is the low redundancy connected to the usage of AS/RS. This results from the often strict association of one automated storage and retrieval machine to a single aisle of the warehouse. In the following work different techniques to raise the availability of the warehouse system by implementing additional redundancy are introduced. A conventional technique mentioned is the method of implementing aisle changing storage/retrieval machines. An innovative method is to develop a system in which each load unit stored in a rack can be accessed from the two aisles surrounding the rack, in other words, two AS/RS have access to each storage unit.

This new technique is introduced and the advantages and disadvantages are elaborated. Throughput-maximizing storage strategies are developed with consideration of the desired maximization of redundancy. The conventional method of aisle changing AS/RS is compared to the innovative one by means of remaining capacity and remaining throughput in case of a breakdown, complexity of the operation strategies and investment to realize the solution. The conclusion helps operators to decide which variant suits their needs best.

KEY WORDS
Automated Storage/Retrieval System, AS/RS, Throughput, Redundancy, Availability, Cycle Time, High Bay Warehouse

1. Introduction

After the just in time movement of factories without warehouses, exists an increasing trend of charging storage capacity caused by the demand for a high ability of delivery. The customers of production and distribution companies especially in the food or spare parts sectors accept no delayed deliveries and require an ability to deliver of 100 percent.

To accomplish these requirements it is necessary to charge the products in warehouses with sufficient capacity for all the loading units and fast access. A good option is the use of high-bay warehouses with automated storage and retrieval systems [1].

Figure 1: AS/RS (Swisslog, Switzerland)

The warehouses generally consist of a number of parallel aisles with high racks alongside each aisle. A storage/retrieval machine, in short S/R-machine, which moves along the aisles, performs storages and retrievals. In contrast to fork lift trucks or very narrow aisle trucks a

S/R-machine can move completely diagonal on the way to the stockyard [2].

But what happens when a S/R-machine in spite of high availability breaks down? In that case an access on the units in the broken down aisle is not possible for the duration of trouble shooting. This can have an effect on the ability to deliver.

To solve this problem there exist different solving strategies. On the one hand side sharing operation strategies can be used to store equal units in different aisles and on the other side the design of the construction can be matched for a redundant access even in breakdown situations.

2. Configuration of Warehouses

An AS/RS consists of one or multiple aisles with high racks on each side. It is characterized by a high storage capacity per floor space. The S/R-machine moves on rails that are mounted on the floor and the ceiling.
In many applications the S/R-machine is confined to one aisle. The advantage is a high throughput.

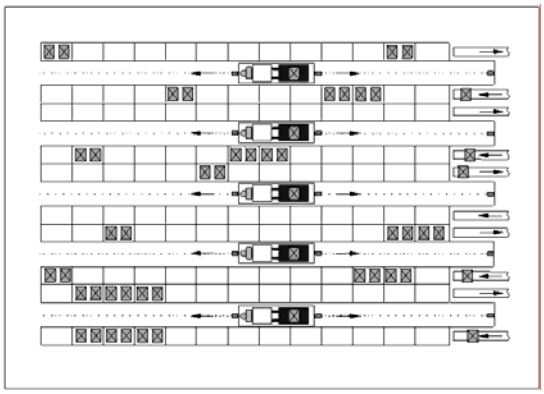

Figure 2: Warehouse with aisle confined S/R-machines

Another possibility is a system where the S/R-machine may move between aisles by curves in the rails that connect the aisles.

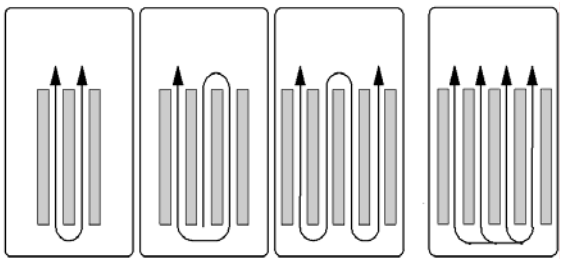

Figure 3: Warehouse with curve-driving S/R-machines

The third used construction type is a warehouse with a shuttle device that transfers the S/R-machine between the aisles. A feature of the last mentioned systems is the low necessary investment because of a small number of S/R-machines. In return the time for aisle changing reduces the throughput of these systems.

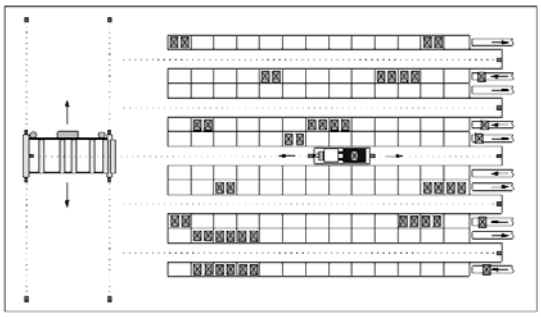

Figure 4: Warehouse with a shuttle device

The dimension of high-bay warehouses is nearly unlimited. They can reach heights up to 50 meters and systems longer than 300 meters have been realized. The capacity includes multiple thousands of pallets.
As load handling devices telescopic forks are mainly used in warehouses with pallets. But they only allow a lengthwise storing of the pallets and at maximum two pallets back-to-back. If two pallets are stored behind each other, there exists no direct access to the second one. This causes stock transfers in the warehouses and reduces the throughput.

Another alternative is the usage of a channel storage system. In this system the racks beside the aisles contain channels with multiple pallets in series, instead of single pallet places. Channel vehicles are able to store pallets lengthwise and in cross direction. Thus it enhances the storage capacity per floor space with the disadvantage of non direct pallet access. The S/R-machine transports the channel vehicle to the destination channel with the ordered pallet. Afterwards the channel vehicle drives along the channel, lifts up the ordered pallet and brings it to the S/R-machine. After that the S/R-machine transports the channel vehicle with the pallet on to the retrieval point [3].

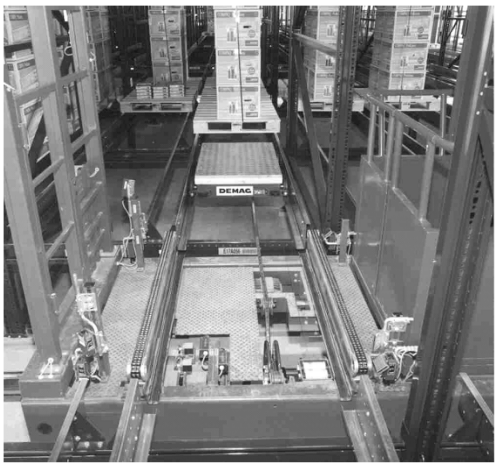

Figure 5: S/R-machines with channel vehicle (Mannesmann Dematic, Germany)

If the direct access to the pallet is blocked by pallets arranged in front of, stock transfers are necessary. Warehouses with channels are last in first out systems. That's why they are often used to store a lot of pallets with the same product.

Beside pallets diverse other loading units can be stored in AS/RS. For these units exits multiple special load handling devices.

The most commonly used S/R-machines are ground-based. Latest developments lead to S/R-machines above-ground. As there are no constructions on the floor this technology offers new scopes for design. The Transfaster technology is an example for a S/R-machine above-ground.

The Transfaster is mounted at the highest rack bar of both racks beside the aisle like a gantry crane and moves on two rails along the aisle. The load handling device is fixed on a platform which is mounted over four wires with the vehicle. For this kind of S/R-machines exist a shuttle device to change the aisles, as well.

Figure 6: Transfaster (Westfalia, Germany)

S/R-machines are a very reliable storage operating technology with availableness over 98 percent and in the rare situation of a breakdown a manual operation is possible.

Table 1: Selected Specifications

Specification	S/R-machine	Transfaster
Altitude	up to 50 m	up to 18 m
Horizontal speed	4.0 m/s	4.0 m/s
Vertical speed	2.0 m/s	1.0 m/s
Load handling device	telescopic forks, channel vehicle	telescopic forks, channel vehicle
Complete diagonal movement	yes	yes
Ground based	yes	no
availableness	more than 98 %	more than 98 %

3. Operating

The storable loading unit arrives at the input station and waits on a buffer place until the machine transports the unit to the stock ground, given by the warehouse management system. This system manages the inventory and the loading units as well. It knows the stockyard of each unit and unassigned storage space. The warehouse management system defines the stockyard for the unit by using optimization strategies and has to balance the workloads of the S/R-machines. Thereby fast-moving items shall be stored near the input or retrieval station. If an AS/RS consist of several aisles with a S/R-machine in each aisle, the throughput of the whole system can be improved by balancing the workload over the S/R-machines while the products are distributed over the aisles, so that the sum of the turnover rates is approximately equal in each aisle.

At warehouses with aisle-changing S/R-machines the transfers of S/R-machines between the aisles shall be avoided because it takes time and causes less throughput.
In untroubled times, when a maximum throughput is not demanded and only some few storages and retrievals are needed, the AS/RS reorganize themselves. Thereby the loading units are relocated to stockyards with path and time advantages for future retrievals.

4. Ability to Deliver increasing Strategies

An ability to increase the availableness of the warehouse system is to reduce the mean time to repair. Within the sale contract with the vendor of the AS/RS, a supply contract can be covenant, which guarantees a short reaction time of a service technician, in case of a breakdown. It is also possible to store all critical spare parts in a consignment warehouse on-site, so that the own well trained staff can repair the S/R-machine in short time. This can reduce the mean time to repair considerably [4].

At applications with aisle confined S/R-machines exist the problem that if a S/R-machine breaks down, the loading units of the affected aisle can not released from stock. This problem can be bypassed if multiple loading units of the same product are distributed over the aisles, so that another S/R-machine can retrieve the ordered product. However this strategy demands a number of equal loading units, so that this product can be stored in different aisles.

But what can be done if only one loading unit exists from the ordered product or a special unit is needed and the appropriate S/R-machine is out of order? In this case a redundancy of the warehouse system can be enabled by intelligent constructions.

5. Ability to Deliver increasing Constructions

Warehouse systems with aisles-changing S/R-machines enable in general a higher redundancy than systems with aisle confined machines. But this requires a minimum of two S/R-machines. If one machine breaks down and the driving engine is still working, the machine can manually be moved back to a rear section of the aisle. Afterwards the aisle can be used with another working S/R-machine.
Aisle confined machines can not change the aisle so another option is needed to increase the redundancy of the system. An innovative method is the construction of a system in which each stored loading unit can be accessed from the S/R-machines in the two aisles surrounding the rack. In this kind of warehouse a loading unit can be handled by two different S/R-machines so a redundancy is given. Thereby the outer racks are an exception. The construction of these warehouses needs an optimization of the number of loading units stored in a row between two aisles. This is affected by multiple factors. A higher amount of loading units in a channel requires fewer S/R-machines and saves investment. The aisle area can be reduced as well, so that the capacity per floor space increases.

In return these advantages imply a lower throughput because of a smaller number of S/R-machines and more stock transfers. Likewise the load handling device alternatives are reduced because with a telescopic fork only two pallets can be stored in a row.

A construction alternative with a redundancy of 100 percent and a high performance represents an AS/RS with only one or two loading units in a row between two aisles. With this alternative the construction of warehouses with a redundant access to all the loading units, excluding only the units in the outer racks, is possible. If in the outer racks a redundancy is necessary as well, it is possible to use the aisles as sidewise borders of the warehouse. The number of equal loading units does not affect the redundancy.

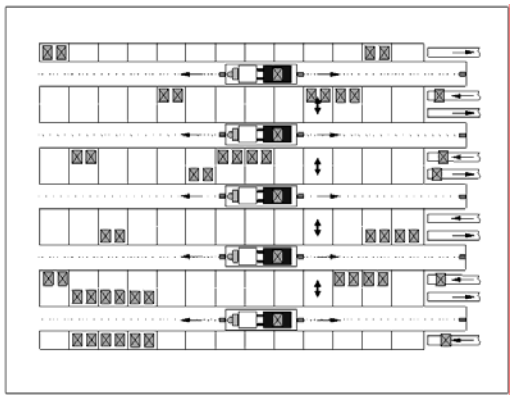

Figure 7: Redundant Warehouse with Access to Loading Units from Two Aisles

After the construction of a full redundant warehouse the successive systems come to focus, specially the prestorage area. At redundant warehouses with aisle confined S/R-machines shall also exist a place of dispatch for each aisle with a redundant connection up to the goods issue. Frequently a traverse car is installed in the prestorage area as connection technology between the places of dispatch to the continuative conveyors. This leads to a bottleneck element with no redundancy. This problem shall be avoided with a redundant conveyor technique like automated guided vehicle systems or automated electric monorails. These systems consist of multiple vehicles which can pick up the loading units at

each aisle and can transport them directly to the goods issue.

6. Conclusion

In critical areas of production and distribution, for example warehouses, redundant systems are particular important, to satisfy the customer requests of a permanent ability to deliver. As there are no systems with availableness of 100 percent, these systems shall be constructed as full redundant systems. In this paper different variants to increase the availableness with operative or constructive activities have been described.

Table 2: Redundancy Increasing Options

Operation strategy	Construction
service contract with short reaction time	aisle-to-aisle transfer of the S/R-machine
on-site spare parts warehouse and well trained own technical staff	access to the loading units from two aisles
transverse distribution	redundant conveyor technique in the prestorage area

A new technique with channel vehicles is introduced and the advantages and disadvantages are shown. The conventional method of aisle changing AS/RS is compared to the innovative one with access to the loading units from two aisles, which is characterized by less throughput but less breakdown sensitivity. The operators have to choose the best variant for their application and have to weigh investment against redundancy and ability to deliver.

References

[1] L. Schulze, R. Vogelsang, Keine Logistikkette ohne Lager, *Logistikwelt 2002, 9*, 2002, 6-48.
[2] D. F. Ross, *Distribution – Planning and Control* (Chapman and Hall, New, York, 2000).
[3] H. Martin, *Transport- und Lagerlogistik* (Vieweg, Wiesbaden, Germany, 2006).
[4] L. Schulze, M. Lucas, Logistics and Automation - State of the Art and Trends in Europe. *Greater China Supply Chain Logistics Forum and Academic Conference*, Nanjing CN, 2005.