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**Conference Paper**

## Adaptive Intra-Logistics

**Provided in Cooperation with:**

Hamburg University of Technology (TUHH), Institute of Business Logistics and General Management

*Suggested Citation:* Yousefifar, Ramin; Popp, Julian; Beyer, Theresa; Wehking, Karl-Heinz (2015) : Adaptive Intra-Logistics, In: Kersten, Wolfgang Blecker, Thorsten Ringle, Christian M. 978-3-7375-4059-9 (Ed.): Innovations and Strategies for Logistics and Supply Chains: Technologies, Business Models and Risk Management. Proceedings of the Hamburg International Conference of Logistics (HICL), Vol. 20, epubli GmbH, Berlin, pp. 285-304

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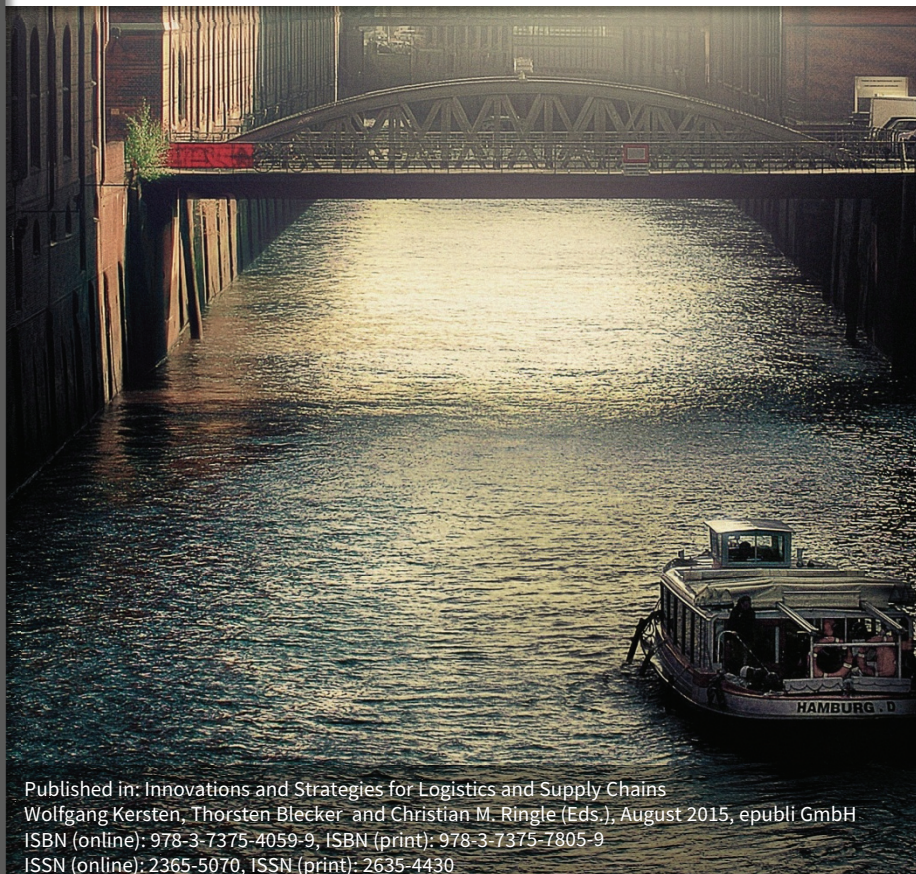


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# **Adaptive Intra-Logistics**



# Adaptive Intra-Logistics

*Ramin Yousefifar, Julian Popp, Theresa Beyer and Karl-Heinz Wehking*

Many Intra-Logistics systems are designed over the course of several years in order to ensure the logistical supply of an assembly or production area for a fixed number of years. In the past this approach was economically successful. However, today's globalized markets require different procedures. Adaptive Intra-Logistics systems will be required in the near future in order to ensure adaptability to changes in assembly or production (e.g. volume fluctuations, additional products, changed geometry of products) without requiring costly new investments. The adaptability of these systems could be achieved through modular design and dynamic planning. In this paper a new planning methodology for Intra-Logistics systems is described. This planning methodology is based on features of Multi-Agent Systems such as self-organization. These characteristics of our planning methodology make it particularly suited for autonomous logistics modules and contribute to the adaptive Intra-Logistics systems. Furthermore, the current literature on the technical alternatives for reach adaptive Intra-Logistics is explored. Especially modular design is key to coping with rapidly changing production environments. Therefore, four different new logistics concepts, which have been selected using a rating matrix and questions catalogs, are presented. These concepts were verified and validated in simulations.

**Keywords:** Flexible Intra-Logistics, Modular Design, Multi Agent System, Automobile Logistics

## 1 Introduction

Intra-Logistics represent the internal flow of materials between different logistics nodes in a company - from materials handling in the production process to distribution centers right on up to airports and seaports - as well as to the corresponding flow of information (CeMAT 2015). Optimization of the Intra-Logistics is essential to ensure economical, high-quality and time-efficient operations in manufacturing. Intra-Logistics costs are a substantial component of the total costs in manufacturing. Tompkins et al. (1996) estimated that in a typical manufacturing operation, 25% of the number of employees, 55% of all plant area, and 87% of production time are assigned to Intra-Logistics systems and it accounts for between 15% and 70% of the total cost of manufacturing a product. Efficient operation of appropriate materials and information flow methods can contribute towards a reduction of manufacturing cycle time and work-in-progress inventory cost. An efficient Intra-Logistics system supports the production process, increases production and system flexibility, provides effective utilization of manpower and decreases lead time. The modern Intra-Logistics equipment's such as automated guided vehicles (AGV), electric monorail systems (EMS), pallet conveyors, rail-guided vehicles (RGV), transfer cars, and baggage handling systems, as well as sorters, automated storage and retrieval systems (AS/RS, stacker cranes) and shuttle systems are now widely used in many industries worldwide. The fast-growing sector of Intra-Logistics, consisting of equipment manufacturers, warehouse technology producers, software developers and even complete system providers facilitates optimum solutions for every individual application across many different industries (CeMAT 2015).

The competitive nature of global manufacturing forces companies to seek innovative approaches for improving and optimizing their processes. Due to large production numbers and complex products, the automobile industry always requires innovations in Intra-Logistics to reduce cost and improve productivity (Trappey 2010). Therefore our innovative Intra-Logistics concepts focus on this industry.

One of the key factors in manufacturing facilities, which are constantly being improved, is the design of adaptable processes that enable stable performance under changing conditions. In recent years much literature has been written on adaptable processes. The majority of the published articles deal with adaptability of manufacturing systems and Supply Chains (Barad 2003). Research on designing adaptable Intra-Logistics systems has received little attention. A truly adaptive Intra-Logistics requires a shift in approach. For most manufacturing companies, this means:

1. Reinventing Intra-Logistics concepts
2. Rethinking Intra-Logistics planning approaches

At the Institute of Logistics and Material Handling at the University of Stuttgart we have identified the need for change in the production logistics due to product changes, individualization, shifting customer needs and global supply chains. To develop innovative approaches to solving these challenges, we initiated two projects. The first (DFG project) focuses on the theoretical path of Intra-Logistics planning using agent approaches and the second project focusing on using the theoretical approach to create innovative Intra-Logistics systems for the heavily cost damaged automobile production logistics. In this article, these two important issues in developing adaptive Intra-Logistics systems are to be addressed. This includes the

dynamic planning of Intra-Logistics systems (2) as well as modular design (3).

## 2 Planning of Intra-Logistics Systems

As mentioned in section 1, Intra-Logistics systems will have to behave like dynamic systems in the future. Organization, structure and features of Intra-Logistics systems should change continuously depending on the market and company requirements (Marrenbach 2008). It is acknowledged that the planning of Intra-Logistics systems design is highly complex due to a huge amount of technical and organizational implementation possibilities. The authors tackled this complexity by developing sequential iterative planning approaches. In the literature, planning methodologies with different steps can be found (Gu 2010). There are four common themes running through all of these methodologies:

1. The planning process starts with the conceptual and data acquisition.
2. Based on the result of the first step the planning team selects a few appropriate cost-effective alternatives.
3. At the end the best alternative is selected and then worked out in detail by means of simulation and other operation-research techniques.
4. The planning process finishes with the call for proposals and the selection of suppliers.

These steps are interrelated and a degree of reiteration is mostly necessary. Although many researches into the computer aided design techniques used

within each of the steps was undertaken, the planning results are still highly dependent on the expertise of the planner, the development time is still long and the planning procedure is inflexible in dealing with changing requirements. These disadvantages lead on the one hand to uneconomic manufacturing systems and/or on the other hand to Intra-Logistics-systems that cannot match their respective required dynamic logistics service levels.

For several years, engineers of systems composed of a large number of elements have investigated solutions where those systems are composed of several (simple) elements which collectively produce 'something' more complex at the global level. This is what is frequently referred to as agent-oriented methodology. Our research applies this methodology to the planning of Intra-Logistics systems. This paper proposes an agent-based model for dynamic planning of Intra-Logistics systems in the next section.

## **2.1 Dynamic Planning With an Agent-based System Planning**

Intra-Logistics systems are vastly different from one another. However, most of them share some general pattern of material flow including: receiving area, issuing area, assembly area, picking area, packing area etc. In these functional areas Intra-Logistics systems move, store, assemble, identify, label, separate, secure and sort goods. These groups of activities are referred to processes. These processes are executed by resources, such as forklift trucks, conveyer systems, storage racks and barcode scanners. In

this context, an Intra-Logistics system can be modelled as a swarm of interacting components. The planning process based on this decentralization could be realized as follows:

First the planning tasks and goals are fixed, the planning data is collected and analyzed and the planning object is functional decomposed. Each functional area in the system is described by its input and output stages. Goals and requirements are broken down and connected to the functional areas. The result of the first part is a functionally decomposed description of the system including article flows, requirements and stages. In the second phase the synthesis of the system takes place. The system concept is developed in a bottom up direction by cyclic composition and configuration of functional areas, processes and resources. Based on compatibility checks the processes are connected with resources. The needed capacity of the function element is calculated. At the end of the composition and configuration procedure the solutions are ranked in a list. In the third phase the chosen concept is worked out to execute a call for proposals and a supplier selection. The key unit of this model is the intelligent planning object (IPO), which mimics the properties and behavior of requirements, resources processes and strategies. These IPOs are able to organize themselves autonomously and to interact internally and externally via standardized ports/protocols. Furthermore, one super-IPO assesses the final Intra-Logistics system configurations and transforms user requirements. Defining the required intelligence of the IPOs needs an understanding dynamics and providing means for managing the complexity (Wehking 2011).

To realize the decentralized planning concept, multi-agent systems are particularly suitable. To support the planners of an intralogistics system,

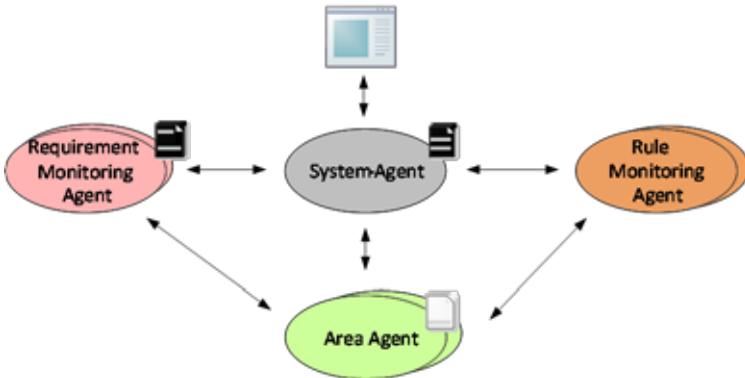


Figure 1 Top-level concept of the agent-based approach

agents can represent various parts of the system. Predefined engineering knowledge can be integrated into the multi-agent system. This provides the agents with the possibility to create realization proposals, which can be taken as baseline for further detailed planning. In Figure 1, the hierarchic structure of the different agent types is shown.

At the highest level there is the system agent. The system agent interacts with the planner and loads and evaluates the requirements, which are specified by the planner. Moreover, based on the given requirements the system agent defines the necessary functional areas and instantiates the respective area agents. The system agent creates an individual agent for each functional area, even if a functional area of the same type is already present. After generating adequate solutions to the specified problem, the system agent also post-processes the data before the output in form of evaluated realization possibilities is displayed. Besides the system agent, there are also other top-level agents, the requirement monitoring and rule

monitoring agents that constantly monitor the fulfillment of the specified requirements and global rules, which are needed to be kept for the correct development of an Intra-Logistics system. These rules include, for example, which functional areas are needed. After generating the required area agents, each agent starts coordinating its respective functional area and identifies different possible sequences of the required functional processes and evaluates them since all realization possibilities have to be checked. These sequences are formed depending on the given requirements and then each potential solution is investigated separately by the area agent. For this purpose the area agent instantiates the demanded resource agents for each sequence and informs them of their respective neighbors. The resource agents represent a resource, which is connected to the required functional process. Each created resource agent then allocates the necessary resources to the corresponding process. To be able to pick correct resource agents, the area agent needs pre-specific knowledge about its corresponding functional area type. The necessary information on the resources required for each function is stored in a database in form of a resource catalogue. The described agent concept of a functional area is shown in Figure 2.

The result of the described process is a large number of resource agents that form a network, since every agent is connected to its neighbors. After their instantiation each resource agent evaluates its represented resource against the given requirements that are made to the system beforehand. A specific requirement for the handling object, for example that pallets have to be transported, would lead to a removal of all resources,

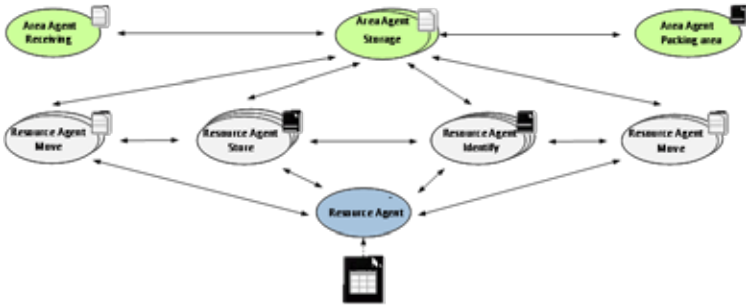


Figure 2 Agent concept of a functional area

which are only able to transport packages. These resource agents inform their neighbors that they are not compatible with the given requirements and switch themselves into a stand-by mode. To reactivate these agents the planner needs to change the systems requirements, which will lead to a reactivation of these agents by the requirement monitoring agent. The remaining of the network is hence a set of active agents, fulfilling the demanded requirements.

As the next step the connections between its neighboring resources has to be checked by each resource agent, to eliminate resource combinations that cannot be connected to each other. Each resource agent assesses the interfaces of its resource with its possible neighbors by matching the defined interfaces according to compatibility rules. For example, if packages have to be removed from a specific warehouse resource vertically, a withdrawal unit, which is only able to remove packages in horizontal direction, cannot be used in combination with this warehouse. If the compatibility check of a resource agent fails which indicates two neighboring resource

with incompatible interfaces, the connection in the network is extinguished. While the resource agents are passing through the check of global requirement fulfillment and interface compatibility with their neighbors the Intra-Logistics system is composed. After the composition, the leftover active resource agents dimension their resources. The knowledge for the dimensioning of single resources is also deposited in a resource catalogue that is part of the knowledge database in the form of dimensioning parameterization rules. Since the compatibility to their neighbors also depends on the dimensioning of the resources, dynamic interdependencies arise between neighbored resource agents. Thus, for example, the choice of the withdrawal unit also depends on the height of an automatic warehouse. These interdependencies can lead to iterative re-dimensioning of a resource and if there is no compatible dimensioning solution with its neighbors, to an activation of the stand-by-mode for the incompatible agent. In the final step, the adaptation is reevaluated by requirement and rule monitoring agents. Within this phase, the planned Intra-Logistics systems can still be adapted quickly to changing requirements, caused for example by increasing individualization of production processes. The final result of this planning procedure is a network of resource agents containing all realization possibilities for the Intra-Logistics system in development. Every path in this network describes one possible realization option. To evaluate the generated solutions even further, these paths have to be extracted and valued according to different parameters, for example to the costs. Other parameters that are also relevant like for example the flexibility could be contrary to other e.g. to the costs. Since these qualitative requirements like ef-

iciency, flexibility etc. usually decide which realization possibility is realized, the system agent interacts with the planner to find out which criteria are more important in the current scenario and ranks the realization possibilities accordingly.

In order to archive optimal realization options, the rules, which are needed to develop a material handling system, are deposited in the knowledge base, have to as precise as possible. These rules should be gathered from a broad audience of experience planners to support each individual planner that is using the support system. The whole planning procedure can then be executed iteratively and in parallel due to autonomous behavior of the agents. The presented methodology also enables a quick adaptation and change of the requirements to re-establish the consistency of the development automatically.

### 3 New Intra-Logistics Concepts

Today's automobile manufacturing systems are stiff and require a high amount of investment and time to allow changes. This leads to difficult situations in times of changing demands for certain models based on economic growth or market crisis. While the production and logistics systems in their basic structure have changed very little in the past 20 years, the customers are getting offered larger amounts of options on a high scale. This leads to high numbers for variants in the production cycle, which can be comprehended from the theoretical number of variations among European manufacturers, for example for the VW Golf =  $10^{23}$  variations (Klug 2010).

Even with the difference between theoretical numbers and the ordered vehicle variations, only two of 1.1 m produced Mercedes A-class vehicles, were identical (Schlott 2005). While manufacturing has to adapt to different handling steps, the logistic needs to provide variant production materials at the right time and in the right place. This brings up the need for more flexible processes regarding the control and setup of Intra-Logistics systems. Some companies that struggle to handle the higher amount of variants prefer to push these problems towards external suppliers, offering a simple and quick solution for the production company, but implying higher costs for Intra-Logistics. Further increases in model and therefore material variants will lead to higher costs. To break with this circle, new Intra-Logistics concepts have to be used. Therefore we have focused on creating extremely flexible and universal Intra-Logistics systems. We used the above described decentralized planning methodology and defined our parameters. Furthermore on the path towards the development of these new systems we conducted an in depth analysis of the current situation as well as the clarification of disadvantages of today's Intra-Logistics concepts in regard to flexibility and high variant productions. Therefore we evaluated Intra-Logistics operation in different automobile assembly plants in Germany. One of the clearest results was the higher number of storage points and handling steps between the arrival at the factory premises and the point of production. The reason behind this system is the just-in-sequence delivery to the place of production. We estimate that these up to seven handling steps and storage points are accountable for a high amount of the total logistic costs. Therefore we developed ten logistics concepts in cooperation with logistics experts from automobile manufactures, focusing

mainly on the reduction of handling steps. Some of these concepts differ only in certain aspects and therefore four completely different approaches can be filtered out. These are shown in Figure 3 and will be described individually in the following chapter. The concepts have been evaluated re-

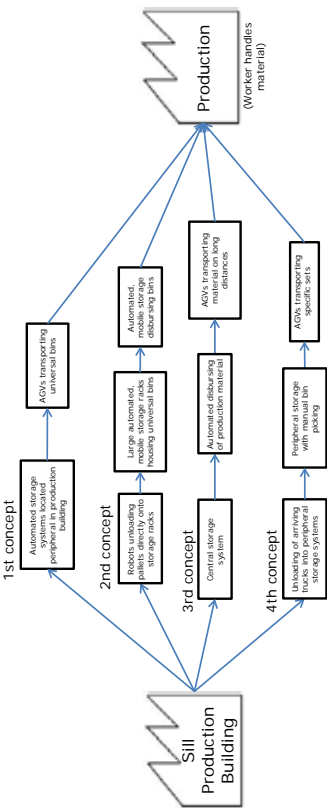


Figure 3 Innovative logistics concepts

garding categories like length of transportation routes for the AGVs, operational safety and potential reaction time regarding changes in the production program. To prove the feasibility of the four new concepts, we used original production data from a large premium automobile company and build up models in the program Plant Simulation, where we were able to simulate different production numbers. All four new concepts were shown as realizable based on the simulation data.

### **3.1 Detailed Description of the Concepts**

The first concept focuses on the smallest number of handling steps out of all concepts. The materials arrive from the supplier and are stored directly in a high rack (HKL) or small-parts storage area (AKL). These storage areas are located peripheral inside the production building, to enable shorter routes for the AGVs. Each storage area delivers only material to the production areas which it is located close to. After receiving a demand signal from the logistics IT-system, the material is released from stock and loaded directly onto an AGV. The vehicle then drives to the production area and delivers the material. During this process, the material is kept inside a universal bin. The worker must only remove the material from the universal bin and the AGV transports the empty bin back to the sill of the production building, where the empty bin is loaded on a truck routed back to the supplier. The described routing for the material is shown in Figure 4.

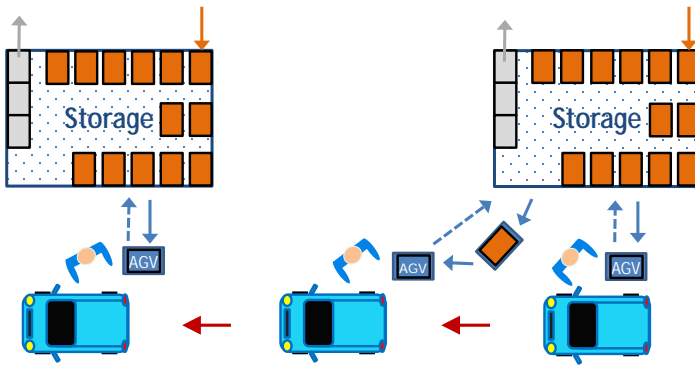


Figure 4 Peripheral storage with AGV concept

The second concept, named automated, mobile storage unit has special advantages for variant productions environments. The mobile storage unit gets loaded with universal bins directly in the receiving are of the production building. The load can be either 48 large universal bins (standardized by the VDA: 600 x 400 x 280 mm) or higher amounts for smaller universal bins (using shelf board as underlayment). The storage then makes itself on the way to the point of production where the material is needed.

This takes places using the built-in drive system and a guiding AGV, named follow-me AGV, which clips onto the mobile storage unit for driving. The clipping facilitates lower total system cost because expensive security systems (laser scanners) and navigation systems (localization, routing and mapping) have to be installed only inside the follow-me AGV and not in the mobile storage unit.

One follow-me AGV can assist multiple mobile storage units with their transport needs throughout the production day. After arriving at the point

of production, the mobile storage unit automatically disburses the universal bins just in real time (JIRT), using a rack feeder, for the present production steps. The collection tray of the rack feeder holds the bin in ergonomic position for the worker. Once all universal bins are emptied, the mobile storage unit moves back to the goods receipt zone for refilling.

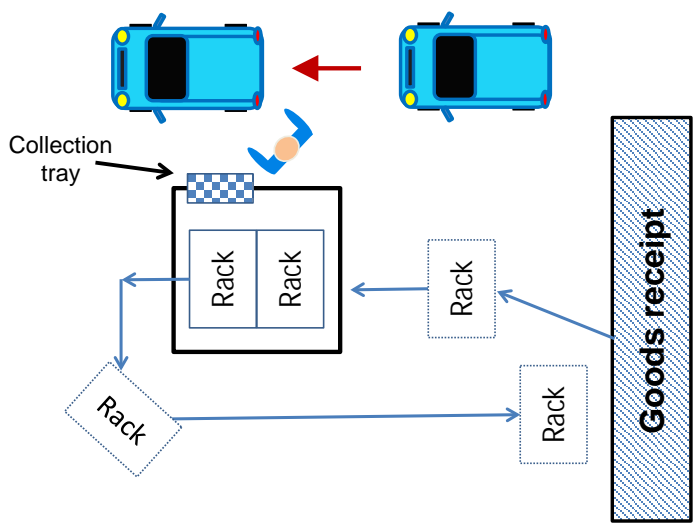


Figure 5 Automated, mobile storage unit concept

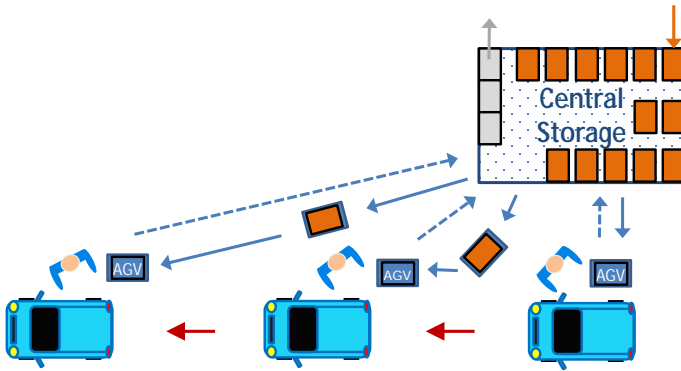


Figure 6 Central storage with AGVs

The idea behind the third concept is the saving of storage space. Using a high rack warehouse, the floor space required for provision of the material can be reduced. However the AGVs have to cover larger distances between the storage and the point of production where they deliver the material in the universal bin. The information for the release of the bin from the stock is initiated by the logistics system. Afterwards the high rack warehouse disburses the universal bin to the AGV.

The AGV drives to the production, the worker takes out the material and the empty bin gets transported back to the sill of the production building, ready for transport to the supplier. The concept is illustrated in Figure 6.

The fourth concept picks up the idea of specific production sets either by universal bins or directly with the material. In a picking area the needed materials are loaded onto a rack which itself stands on an AGV. When the demand signal from the logistics systems is sent, the AGV with the filled rack on top drives towards the first production station. Afterwards the AGV

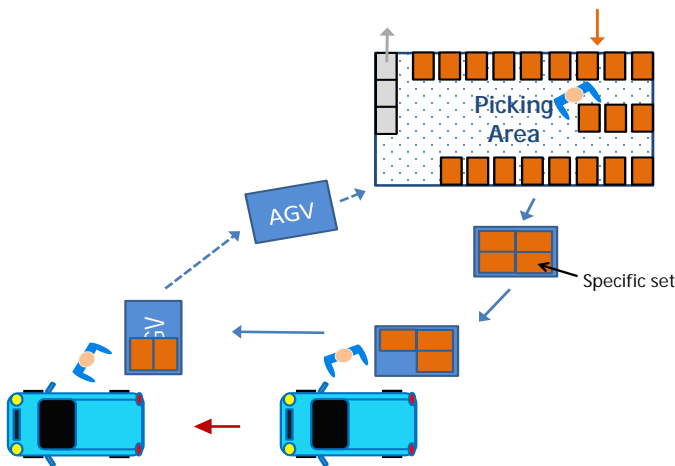


Figure 7 Specific set concept

with the specific set follows the production for a certain number of stations, depending on the size and amount of needed materials. After the last item or material has been taken from the rack or the universal bins, the AGV drives back to the central storage ready for the next routing. The described cycle is shown in Figure 7.

The four described logistics concepts are modular and therefore compatible with each other. In the second half of our project we are working on a selection tool, which suggests the optimal Intra-Logistics concept based on frequency, size and variation of the material together with production numbers. To understand the selection process in the next chapter, the different new Intra-Logistics concepts and their systems can be seen as agents. The results could be the following: Production station 1, 3 and 5 receive their material from systems using the first concept while the stations

2 and 4 have certain characteristics which make the third logistics concept the economical, optimal choice.

## 4 Summary

In this paper we described our current work with logistics modules and modular planning. The idea is the combination of different logistics concepts depending on the individual production station, the amount and variation of material with the aim of achieving higher flexibility and adaptability. Using different planning methods, we will be able to select the most suitable Intra-Logistics concept as well as the optimal storage type. This will lead to cost reduction in the Intra-Logistics and improve flexibility and adaptability. As described in chapter 2, we are working on the creation of a module catalogue selection tool, which should help in identifying the most suitable Intra-Logistics concepts for a specific production station based on material data. Later on the tool will be extended towards including a feasibility study based on controlling numbers from today's logistics concepts.

## Financial Disclosure

The projects described in this paper are funded by the Deutsche Forschungsgemeinschaft (DFG) within the research project DEPIAS (WE 2187/27-1 and GO 810/32 - 1) and the state of Baden-Württemberg within the research project „Neuausrichtung der Produktionslogistik für die Automobilfertigung für eine bezahlbare Elektromobilität“.

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