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Innovative logistics concepts for a versatile and flexible manufacturing of lot size one

Ali Bozkurt[1], Manuel Hagg[1], Robert Schulz[1]
[1]Institute of Mechanical Handling and Logistics, University of Stuttgart, Stuttgart, Germany

Abstract

Due to the high amount of car models and the increasing number of variations in the premium car segment, production logistics in the automobile industry will face new challenges. Conventional logistics concepts such as Henry Ford and Frederick Taylor's conveyor technique will become rare. While conveyors are best-practice for high output and economical production, they are inflexible with high variations. Moreover, an assortment of different parts have to be provided at the line, which results in space constraints and inefficiency in increasing product variety. Hence, it is necessary to focus on contemporary logistics concepts and equipment in order to cope with customer demand when producing in lot size one. Therefore, various logistics concepts and components have been developed by the Institute of Mechanical Handling and Logistics (IFT) of the University of Stuttgart over recent years. The new logistics concepts are more versatile and enable a more flexible and changeable production logistics for a wide range of different products. The aim of this study is to provide an overview of the current situation of the innovative production logistics concepts and describe possibilities for further developments.

Keywords

Production logistics control; economic efficiency; automobile production; material handling, versatile logistics

1. Introduction

Since 1913, automobile production has been characterized by Henry Ford and Frederick Taylor's moving assembly line system, which was a great invention for production methods at that time [1]. The assembly line system was an economic method to produce homogenous products in high quantity and contributed to a great development in the automotive industry. Because of today's social trends like the growing demand of individualization in the premium car segment and the development of alternative drive units e.g. electric or hydrogen drives, manufacturers have to deal with much more variety and complexity [2–4]. For example, the latest Audi A3 was available in $1.1x19^{38}$ possible configurations, which leads to a smaller amount per variant and up to lot size one [4]. In addition to other key issues, like volatile sales figures, the automobile industry will go through a transformation process in the next few years. Therefore, manufacturers have to consider new ways of production to overcome these challenges and allow a new level of freedom and the simultaneous production of different models and variations within the same factory [3–5].

In consideration of those challenges, new production concepts like the matrix production, flexible cell and fluid production have received much more attention over recent years [4,6]. In this way, the new production approaches imply a demand for flexibility and economic production with a high amount of variants [4,6].

However, the introduction of new production approaches has also led to a change from conventional logistics concepts to contemporary innovative logistics concepts. In the automotive production process, material supply takes place at the point of assembly. Small parts are supplied in small load carriers or in boxes. Larger and valuable parts are supplied in large universal bins. In this concept, the assembly worker picks all the necessary parts from the defined storage racks [7]. In most cases, gravity flow top-up racks are used. Each bin in this case is sequenced with the production cycle and, if the bins are empty, new carriers with parts will be requested by the consumption-driven KANBAN concept [7,8]. Inspired by Japanese car-makers' success, production logistics in the automotive industry is characterized by the logistics concepts just in time (JIT) and just in sequence (JIS) [8]. JIT is an approach to minimize the inventory by delivering parts exactly when they are required. JIS focuses on the management of high numbers of different parts by sorting and providing them as previously scheduled [9]. However, this concept is mainly characterized by space constraints and inefficiency by increasing the amount of different parts [9].

There is no denying that the logistics concepts JIT and JIS are good methods for reducing costs and the amount of storage, but the expected increase of several variations will make them more difficult to manage with conventional logistics concepts [10,11]. For this purpose, the IFT is working with partners from industry on the development and validation of new production logistics concepts and components [12–18]. Thereby, the focus is on automotive production, but some of the concepts can also be transferred to other industry sectors.

The remainder of this paper is organized as follows: Section 2 provides an overview of the state of the art and presents developed logistics concepts and components; Section 3 deals with strategies for production logistics control as well as possibilities for novel economic efficiency methods; Section 4 concludes the key points of this paper and provides an outlook.

2. State of the art

The increasing amount of different parts at the point of assembly and new production concepts such as those introduced in section 1 have brought the established concepts to their limit**.** Therefore, new logistics concepts and components have evolved. Some of the concepts and components have already been implemented in automotive production processes and others are being researched and have to be tested under real circumstances [19,20].

2.1 Production logistics concepts

Set concept

The first concept is the set concept or kitting concept in which specific sets are bundled for each vehicle and supplied with a shopping cart at the point of assembly. In this case, the parts are within the reach of the assembly worker. The set concept is especially suitable for all small and medium sized parts which are needed for a specific number of assembly stations [7,8,15]. After the set building process, each set follows the allocated vehicle in shopping carts as the vehicle gets assembled at a defined number of assembly stations. Bigger parts will thereby be transported in the traditional way by larger bins or power and free conveyor systems. When all the materials are taken out, the empty shopping cart will be transported back to storage or to the supplier for further refills [3,7,15]. The main advantage of the concept is that all the necessary parts are supplied in the right order of the assembly and there is no necessary additional time for searching and identifying material or walking, which results in a better cycle time and efficiency in the production process [14,16,18].

Single Autonomous Guided Vehicles (AGV) concept

The next concept is the use of small, single and economic AGVs for the material transport. Each bin carrier will be transported by a single AGV to the assembly stations. Thereby, the paths for the AGVs are planned by using navigation software [16,17]. After the removal of the load carrier, the AGV will be routed back to storage for a new transportation order [17].

Mobile supermarket

The basic idea of the "mobile supermarket" production logistics concept was developed by Wehking and Popp [15] and is based on several components, designed by Hofmann [12]. Each component can be used separately, but can also be ad-hoc synthesized and build in cooperation the mobile supermarket concept. The mobile supermarket concept includes the following components: rack units for the storage of load carriers and a transportable automatic rack feeder for the loading or unloading of the load carriers [12].

A single AGV will be applied to transport the mobile racks to the assembly stations [14]. Due to the well-defined storage locations and the coordinated automatic material supply, the assembly worker will only be supplied with the necessary parts, which reduces the possibility of errors. Another benefit with this approach is that a large number of different parts will be supplied at the exact moment of the assembly, which is a further advantage compared with the JIT and JIS concepts. Moreover, just-in-real-time logistics (JIR) enables the sequencing of the next required parts at the very last moment without a fixed delivery time and exact defined storage location. The differences between JIT, JIS and JIR are shown in Figure 1 [12,14].

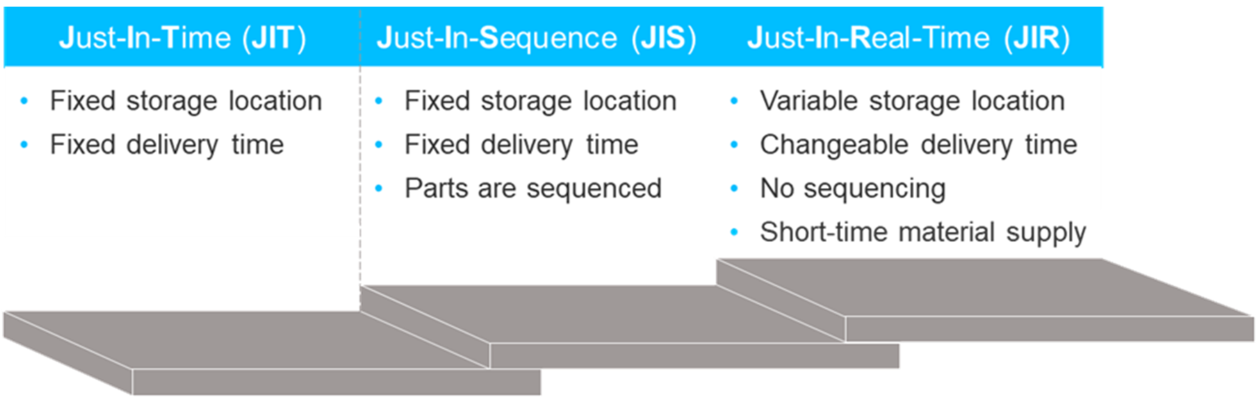

Figure 1: Just-In-Real-Time (JIR) logistics [18]

2.2 Logistics components

AGV

The AGV, which is shown in Figure 2 is a special conception of the IFT and can be applied for several transportation processes. The modular design of the AGV allows the transportation of large parts, work pieces, assembled parts as well as the transportation of racks (Figure 2). The modular design of the AGV is therefore an approach to reduce the amount of different AGVs in production [12].

Mobile assembly platform

For a better value-adding logistics process in automotive production, Hofmann [12] has developed a disruptive innovation called the "mobile assembly platform". The mobile assembly platform hosts an area for assembly workers as well as a docking system for mobile robots [15]. Due to this, production logistics will undertake tasks that are associated with being part of the assembly sector, using a traditional understanding of assembly and production logistics. As a result, the synchronization and integration of logistics and assembly processes leads to value-added production logistics [12]. In contrast to conventional line technologies, the mobile platform vehicle can be discharged out of the assembly process in the case of a quality issue or other production issues such as supply bottlenecks [12]. After solving the issue, the mobile platform can be incorporated back into the assembly process. The mobile assembly platform can also be applied for the production of different models and variations from different manufacturers [12].

Double skid system

The Double skid system, which was designed by Weber and Wehking [17], can be used for the transportation of pallets. Due to the special design, the two forks drive in parallel without being connected, can drive under each standardized Europalet and can lift the pallets up. The double skid system is appropriate for the transportation of large and heavy parts with a maximum weight of 1000 kg. An integrated spindle drive is applied in this case for handling the necessary lift, drive and steering motions [18].

Figure 2 shows all the described components developed at the IFT. The prototypes of the components can be visited at the research campus Active Research Environment for the Next Generation of Automobile (ARENA2036) at the University of Stuttgart. The components for the supermarket concept including the racks and the automatic rack feeder are shown on the left side. The mobile assembly platform is in the middle and the single AGVs and the double skid system are shown on the right side.

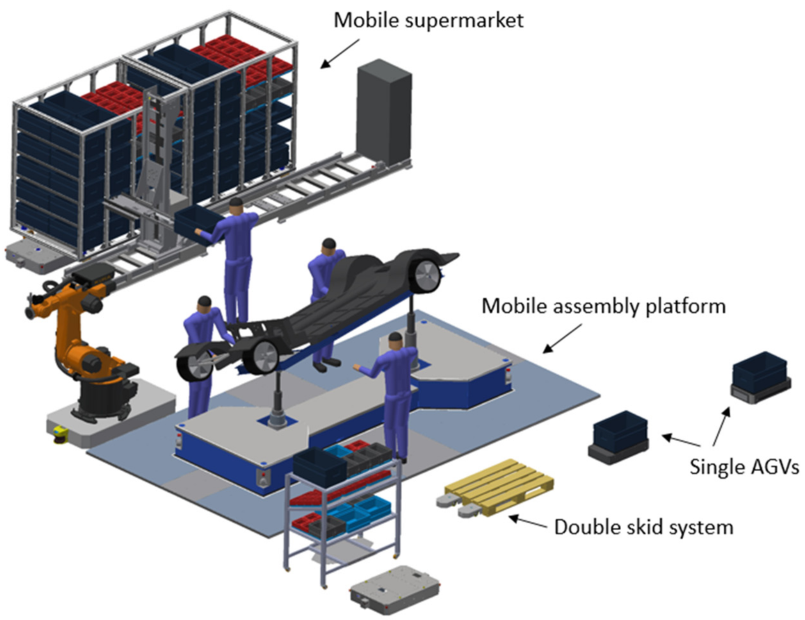

Figure 2: Innovative logistics components [18]

3. Further development of production logistics concepts

3.1 Decentral production logistics control

Within versatile and flexible logistics and production systems, the redesign of assembly stations, process planning or control as well as target-oriented decision-making is challenging [21]. Thereby, a system can be defined as groups or sets of connected, interacting or interdependent elements with certain relationships that form collective entities. Usually, a system consists of elements, interconnections and a goal [22]. System elements like a single AGV can be defined as the smallest system units. Interconnections describes the relationship between elements and determines the system structure [23].

The complexity of controlling and planning a modern production and logistics system is increasing significantly. The key drivers of complexity are based on external aspects like the volatility of the procurement market or the high number of companies involved in the supply chain structure as well as internal aspects such as an increased degree of freedom in production logistics processes [24]. In the first instance, using modular intralogistics components as described previously and shown in Figure 2 will further increase system complexity. One reason for that is that the higher number of interconnections and interfaces between system elements leads to a higher coordination effort because of the rising number of options available in fast-changing production logistics environment. However, these approaches offer opportunities for handling the challenges that logistics and manufacturing systems are facing such as manufacturing in lot size one. However, the impact of decision-making is difficult to estimate because of existing uncertainties within production logistics systems. For example, uncertainty can be traced back to the existence of interfaces and interdependencies between the system elements. An important system in the context of versatile and flexible manufacturing is the AGV system that consists of several elements [25]:

- One or several AGVs
- Guidance control system
- Devices for position determination and localization
- Data transmission equipment
- Infrastructure and various peripheral installations

Peripherals are built and installed particularly for the usage of AGVs, whereas infrastructure is usually already present in the environment and needs to be considered when operating the AGVs [26]. The AGV guidance control systems are responsible for the coordination of the system’s vehicles and the integration of the AGVs into internal processes [27]. In this case, coordination means balancing the individual activities of the single elements within the system in respect to an overall objective [28].

However, the tasks assigned to the guidance control system are context-sensitive and depend on factors like the competency of the AGVs, interaction with a higher level material flow control system or the degree of decentralization. In centralized control approaches, guidance control systems comprise all the relevant tasks like transport order management, vehicle dispatching, travel order processing or further service functions. This also includes coordination and communication with peripherals or mechanical interfaces (e.g. interaction between vehicle and loading aids) and functional interfaces (e.g. information flow such as the data exchange of loading conditions) [26].

For several years, these central control approaches were sufficient. However, with the increasing complexity of production logistics systems, these hierarchically structured concepts have reached their limits. One reason is the availability of different types of AGVs, for example, regarding their navigation principles. In addition, several AGVs from different manufacturers operate in the same environment, which cannot be managed by a single guidance control system due to missing compatibility. Another reason for this is that these approaches are rigid and inflexible due to a central decision-making instance. Therefore, different decentralized control concepts have been developed with the goal of shifting decision-making authority to individual entities [29]. Thereby, system complexity is reduced by breaking down a complex task into several sub-tasks for finding an adequate problem solution. For example, a group of closely spaced AGVs in a production layout independently negotiates who executes the next transport order without interacting with a central instance. A prerequisite for this is that the vehicles or infrastructure has the ability to interact with the required entities being part of the environment or sub-system. Consequently, system components are enabled for target-oriented simultaneous and locally concentrated decision-making.

However, since production and production logistics activities are becoming more and more interlocked, it would not be successful to optimize these sub-systems independently as standalone solutions in the near future. In particular, many current decentralized control approaches address and optimize the objectives of isolated sub-systems such as production or logistics. As a result, the control strategies of these approaches are often based on the minimization of travelling distance and energy consumption of AGVs or optimizing the workload of the transport or manufacturing system [30–32]. One reason for this is the architecture of software products available on the market that often has a modular structure, allowing it to operate independently as a self-contained system. Following this, it is questionable whether decision-making by these control approaches goes along with the strategic goals of the company. Rather, production and logistics need to be perceived as an integrated system with the result of preventing local functional optimization and increasing added value for the company. Thereby, it is conceivable that a sub-system (e.g. fleet of AGVs) accepts a short-term disadvantage (e.g. higher transportation costs) to prioritize the manufacture of a car of an important customer that helps to achieve the company's strategic goals, more than producing cars of other customers, for example, due to a higher contribution margin.

Within a research project, the IFT of the University of Stuttgart intends to break the cycle of isolated and locally concentrated decision-making by developing a dynamic control approach. The decision-making mechanism of this decentral concept focuses upon a company's individual strategic goals. Following this, the decisions made by the production and logistics components go along with the long-term goal of the companies. Since companies have different strategic goals, such as return on investment or revenue maximization, the control strategies developed within the research project will face several possible strategic goals. In the first instance, revenue, operation income, economic added value as well as customer satisfaction will be addressed as company goals. This development is required since the production and logistics system, and therefore the underlying software structures, executes more and more tasks due to increasing system complexity. However, this implies that the decision-making of production or logistics managers and production logistics components should be balanced and address the same goals. For instance, if the quality of managerial decision-making is measured based on achieving company goals, such as a defined economic added value, the decision-making process of the production logistics system should follow that logic as well.

At the moment, different strategies are tested and investigated by using an agent-based simulation approach. A critical success factor is how to deal with data underlying the decision-making process. Here, the short-term action alternatives at the shop floor level should be reconciled with the long-term success of the company. This requires a close interplay of the long-term-oriented Enterprise Resource Planning (ERP) and the short-term-oriented Manufacturing Execution System as well as an integrated consideration of the AGV systems.

3.2 Economic efficiency and decision-making

New logistics concepts are bringing economic benefits compared to the conventional concepts like the conveyor system. For example, conveyor systems are planned and calculated according to the production planning for a product cycle. After the product lifecycle, the logistics components are scrapped and in most cases a further use is not possible. Innovative logistics concepts, in contrast, provide the opportunity to re-use the components. A component such as the single AGV, as shown in 2.1, is designed for the transportation of a wide range of different parts and for several transport processes. In addition, due to the new concepts, there is less storage use for material supply than in conventional supply strategies like top-up racks. Another point to consider is that, due to business model innovations of the logistics component manufacturers in recent years, there are new opportunities for components acquisition.

The logistics components can, for example, be acquired via a leasing model. This opens the possibility to make short-term decisions and react to market demands.

Especially in the case of workload spikes or volatile sales numbers, leasing models should be considered. There are two options for leasing models [33]:

1) The leasing company is an external partner and provides the components
2) The leasing company is an internal business unit or cost center

In most of the concepts, no pre-commissioning process is necessary, which also reduces the handling steps. Moreover, the new concepts also benefit the production process. Due to the material supply at the point of assembly with the JIR concept, the assembly worker can thereby focus on the value-adding processes.

However, for better comparability, not only quantitative factors like investments costs should be viewed. Furthermore, the concepts also show qualitative factors, which are difficult to measure but are assessable for each proposed system [34].

- Scalability: Each concept can be scaled to different lot sizes.
- Universality: Most of the concepts can be used for a variety of products.
- Modularity: The modularity of the components allows the combined use and single use of the components.
- Compatibility: The interfaces of the components enable connections with each other [34].

Most research results show that there are only strategic considerations like investment decisions for logistics components or the outsourcing of logistics processes. However, for most of the logistics concepts in the automobile industry, there is no approach to evaluate and compare the different logistics concepts regarding their costs and characteristics. Therefore, the IFT is working with different partners on the development of new methods to evaluate and select innovative logistics concepts, which will promote a solution for short-term as well as long-term decision-making.

4. Conclusion and outlook

The purpose of this paper is to describe the current situation of the production logistics concepts and components that are needed for a versatile and flexible production of lot size one. One of these topics is the development of a decentralized production logistics control concept that places a decision-making mechanism that focus upon companies' individual strategic and long-term goals. Another topic is the development of new methods that generate more economic efficiency like leasing concepts for production logistics components. Moreover, the next important steps are taking place to establish those concepts and components and test them under real circumstances.

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Biography

Ali Bozkurt (*1991) has been working for the Institute of Material Handling and Logistics at the University of Stuttgart since 2018. He studied Industrial Engineering and Management at the University of Erlangen-Nuremberg.

Manuel Hagg (*1990) has been working for the Institute of Material Handling and Logistics at the University of Stuttgart since 2017. He studied Technically oriented Business Administration at the University of Stuttgart.

Robert Schulz (*1970) is holder of the Chair of Mechanical Handling, Intralogistics and Technical Logistics of the Institute of Mechanical Handling and Logistics (IFT) at the University of Stuttgart. His main research areas range from classic mechanical handling technology to adaptable logistics systems. Schulz studied Mechanical Engineering at the University of Stuttgart and received his doctorate in 2002. He began his industrial career as a project manager for simulation and digital factory planning at Dürr Systems AG and then he moved to AUDI AG.