# Introduction of a Hybrid Control Approach for Automotive Logistics

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*Abstract:* Nowadays, processes of logistics are generally controlled by applying a centralized control approach. However, regarding an increasingly complex and dynamic environment the centralized control approach often turns out to be inflexible and not manageable satisfyingly. To cope with this situation, autonomous control was developed. Though, both control approaches feature advantages and disadvantages regarding their performance and transparency. Here, a hybrid control approach can combine the advantages of both approaches. The paper at hand presents a concept of a hybrid control approach using the example of automotive logistics.

*Key-Words:* - Hybrid Control, Autonomous Control, Decentralized Control, Automotive Logistics

## 1 Introduction

Due to the effects of globalization the general conditions of the automotive industry have changed. Individual customer demands, new drive technologies and innovations have lead to a constantly growing number of product variants [1,2]. In this situation automotive manufacturers focused on their key competences and reduced their vertical integration of manufacturing [1,3]. As a result, complex production and logistics networks have grown within the automotive industry. These networks need to be controlled ensuring efficiency and transparency.

The research project 'RAN - RFID based Automotive Network' funded by the Federal Ministry for Economics and Technology (BMWi) has the objective to increase the transparency of information exchange in production and logistics networks of the automotive industry [4] through the application of RFID (radio frequency identification). Accordingly, a method to generate and to integrate logistics and product-specific information in internal and interplant tools for job controlling is developed within the project. This method bases upon the standardized exchange of process relevant information which allows the control and optimization of the value chain of automotive logistics close to real time. Possible specifications of the necessary control are a centralized and a decentralized approach, afterwards called autonomous control. In addition, a combination of both approaches is possible, afterwards called hybrid control approach.

Due to an environment that becomes more and more complex, central control of logistics processes was observed to be inflexible and not manageable [5]. Particularly complete reschedulings, e.g. necessary due to disturbances or delayed material deliveries, are in many cases difficult. This often NP-hard problem can only be solved in an acceptable effort by heuristics, as the dynamic environment may cause the calculated plan to lose its validity before it can be realized [6]. To cope with highly dynamic conditions an autonomous control approach was suggested within the Collaborative Research Centre 637 'Autonomous Cooperating Logistic Processes: A Paradigm Shift and its Limitations' at the University of Bremen [5]. Here, intelligence and the ability to make decisions are taken from central control and transferred to the logistics objects themselves. This decentralization of decision-making leads to the ability of a whole system to react autonomously and flexible to new requirements of a fast changing environment. Hereby, the robustness and the positive emergence of the complete system can be increased [5,7]. One not finally resolved research task in this context is the comparison of autonomous control and central control in terms of logistics objectives in varying situations of dynamics and complexity. To investigate this question *Windt et al.* suggest a functional interrelation, which compares the achievement of logistics objectives for different levels of autonomous control and complexity [8]. This interrelation is a first approach to examine the limitations of autonomous control. In addition, *Scholz-Reiter et al.* present a method to determine an adequate level of autonomous control and explain different possibilities of decentralization [9]. These developments underline the advantages of a combined approach of autonomous and central control. Here, the levels and degrees of both approaches should be controlled dynamically to fit to the situation. This partial decentralization of control within a logistics system is described as hybrid control in literature [10]. However, hybrid control approaches are not investigated in detail yet especially regarding alternative specifications, characteristics and their impact on the achievement of logistics objectives. This paper presents a concept of hybrid control using the example of automotive logistics.

## 2 Automotive logistics

In the following, the processes of automotive logistics are described at the example of a practical use case that is analyzed within the project RAN [11]. Here, in a worldwide network of the automotive industry, logistics has become increasingly important over the last years.

The scope of the investigation comprises the process of vehicle movement between storage areas and stations of technical treatment at an automobile terminal. Here, next to internal processes and data, the intersecting process steps within the automotive supply chain are relevant for the design of appropriate control approaches. Therefore, the global supply chain is traditionally controlled by a centralized control system.

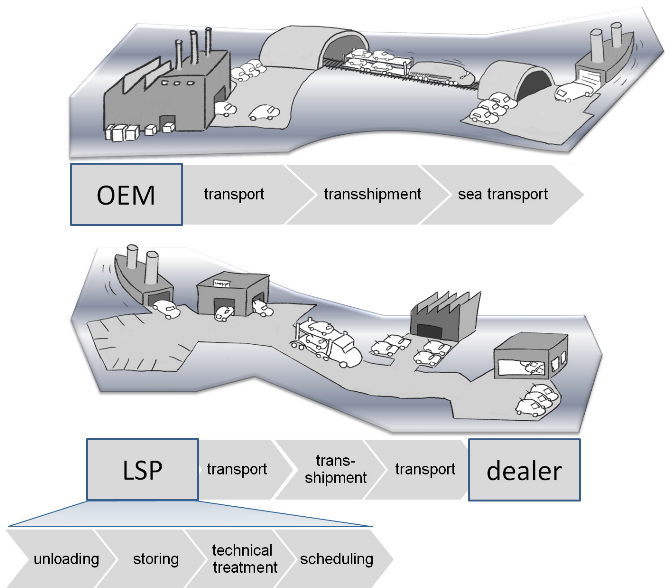


**Fig. 1: Supply chain of automotive logistics. [11]**

The examined process chain (Fig. 1) begins with the first start of the engine at the automobile factory (original equipment manufacturer, OEM). At the end of the assembly line every vehicle is identified by an employee using the vehicle identification number (VIN). The VIN bijectively defines every vehicle. For the following process steps a smart label based on the VIN is placed in the rear window of the vehicle. For every further movement this smart label is used for identification. The vehicles are transported by train from the automobile factory to the harbor. After the transshipment in the harbor from train to car vessel the vehicles are transported to the automobile terminal of the logistics service provider (LSP) in Germany.

Automobile terminals provide various services for vehicles in the range of transshipment, storage and technical treatment. After the vessel's landing the vehicles are unloaded. Terminal employees drive the vehicles to a storage area. Once, the order of a car dealer comes in, requesting a vehicle with certain features, the chosen vehicle proceeds through several stations of technical treatment. After that, the vehicle is brought to the disposition area for transportation to the requesting dealer. Here, the vehicles are transported by truck over a point of transshipment to the car dealers.

The described processes at the automobile terminal are influenced by unsteady arrivals of car vessels on the one hand and unsteady orders of car dealers that define the further steps of technical treatment on the other hand. After unloading, the vehicles are stored on different storage areas. Since there is no definition of further process steps at this point of time, the vehicles are not clustered on these areas. Hence, after an order of a car dealer arrives, the vehicles must be picked out of the storage area.

## 3 Established control approaches for automotive logistics

### 3.1 Central control

Nowadays, logistics processes are mostly controlled by a centralized control system like a manufacturing execution system (MES). Here, central control means that all logistics objects and processes are controlled by one central control system. This also applies for the control of jobs and processes at an automobile terminal like described in section 2. The following description of the applied central control approach focuses on the presented use case, especially on the processes of the logistics service provider.

For the described situation at an automobile terminal, arrivals of car vessels and orders of car dealers determine the processes. This means, that both events cause updates of the job control system. After every arrival of a car vessel, the vehicles have to be unloaded and stored in the available storage areas. Here, the central control system has to decide in which storage area the vehicles have to be placed by using predefined rules which contain an order of priority of all storage areas [12]. Whereas the arrival of a car vessel triggers the storing of cars, the orders of car dealers initiate the removing of vehicles from stock. Furthermore, the order defines the necessary technical treatments and the related stations e.g. for washing the vehicles or charging the batteries. Here, the central control system decides about the sequence, in which the vehicles are processed. Summing up, it can be stated that applying a central control approach the related system is crucial for all processes of the logistics service provider (Fig. 2).

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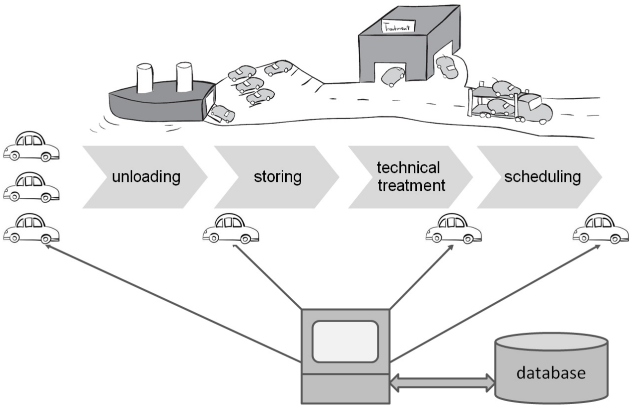


**Fig. 2: Central control of LSP processes.**

The centralized decision-making at the automobile terminal has the advantage that the control of the processes are orientated at global control objectives and dates within the automotive supply chain. Thus, the vehicles are primarily controlled through the processes regarding their adherences to delivery dates. Additional objectives are short lead-times and low inventory. Besides that, central control of the in section 2 described processes has some positive components regarding the transpareny of decision-making. For example, employees are informed about incidents within the centrally controlled processes. This is advantageous, as employees can identify changed terms and conditions (e.g. delayed delivery of materials) and take corrective action. But in an environment that becomes increasingly complex, a central control system also reveales serious disadvantages. For example, a complete reschedule of the job controlling because of changed terms and conditions is in many cases difficult due to the often NP-hard problems.

## 3.2 Autonomous control

Autonomous control was suggested within the Collaborative Research Centre 637 to cope with increasing complexity and dynamic environments, in which the central control of logistics processes turns out to be inflexible [5]. Within the related research, the following definition was worked out: "Autonomous Control describes processes of decentralized decision-making in heterarchical structures. It presumes interacting elements in non-deterministic systems, which possess the capability and possibility to render decisions independently. The objective of Autonomous Control is the achievement of increased robustness and positive emergence of the total system due to distributed and flexible coping with dynamics and complexity." [13]

According to that definition, decentralized decision-making for the described processes of the LSP means that vehicles are no longer controlled by a central control system but every vehicle controls itself through the required processes (Fig. 3) via sending requests to storage areas and stations of technical treatment.

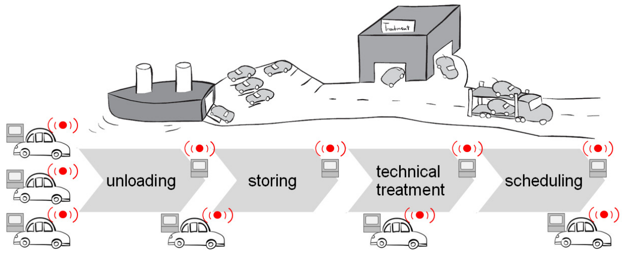


**Fig. 3: Autonomous control of LSP processes.**

For this the vehicles are featured with the ability to gather and to process information about the occupancy of the storage areas on the one hand and with data concerning the job status within technical treatment on the other hand. To enable the information exchange, the vehicles are equipped with smart labels. These smart labels can be identified with a wearable computing system, which is worn by the employees. Yet, the reading operation starts only when an employee sits in the vehicle. With the bijective identification (i.e. VIN), the vehicle is enabled to decide decentrally and autonomous through the wearable computing system. The wearable computing system communicates with other technical systems via WLAN (Wireless Local Area Network) or GPRS (General Packet Radio Service) to process information. One example is the exchange of data between the wearable computing system and the technical treatment station to receive information about the occupancy. Based on autonomous control methods, the wearable computing system has the ability to make decentralized decisions for the vehicle, e.g. to which technical treatment station the vehicle has to be driven next. [14]

Autonomous control methods for the processes of the LSP are already being developed within the Collaborative Research Centre 637 [15,16,17]. Further, the methods are already analyzed regarding their achievement of logistics objectives by simulation studies. Using the example of the storage process, both, the vehicles and the storage areas have their own database and act regarding their own logistics objectives. Each vehicle requires short transfer times in the terminal area and offers each storage area the occupancy of one storage location. Also, each storage area requires occupancy. The storage areas offer the total transfer time to the requesting vehicles. This time consists of the following subtracted times: transfer time from the current vehicle location to the storage area, parking time in the storage area (which depends to their utilization) and the future transfer time to the first technical treatment station. The total transfer time is transmitted to the requesting vehicle, which compares the total transfer times given by the alternative storage areas. The vehicle chooses the best-rated total transfer time. Within the simulation study it has been shown, that, for the vehicle movement processes at the automobile terminal in the period of one year, a total working time saving of 112

work days arises when controlling the processes autonomously. [12,14]
Some advantages of the described processes above are listed in [18], like the fact, that autonomous control leads to an efficient process control and the effort of planning is reduced to a minimum. In addition, changing from centralized to decentralized decision-making pursues the objective to increase the robustness of complex nondeterministic systems [13]. But there are also some disadvantages and limitations of autonomous control. First of all, *Windt et al.* showed that very high degrees of autonomous control as well as very low degrees may negatively affect the achievement of logistics objectives [8]. Moreover, the global centralized control within the supply chain and its global objectives are not considered sufficiently within the autonomous decision-making. Here, logistics objects make their decisions regarding short transfer times on the automobile terminal and short processing times within technical treatments without any consideration of the external given delivery dates. Furthermore, the approach of autonomous control reduces the possibility of the employees to take corrective actions. Thus, there are limitations for employees to monitor autonomously controlled processes.

# 4 Concept of a hybrid control approach

A hybrid control approach promises the combination of the advantages of the central control approach as well as the advantages of the autonomous control approach. Within this section a concept of a hybrid control approach for the described automotive logistics is presented.
Generally, there are different possibilities to interpret hybrid control. On the one hand, a system can be controlled hybridly meaning that central and autonomous control coexist, both referring to certain processes. The ratio of this coexistence is described in literature as the degree of autonomous control [8]. On the other hand, hybrid control can be interpreted as the central control of strategic processes and the autonomous control of operational processes. However, within this research the hybrid control approach is interpreted as the dynamic coexistence of centrally and autonomously controlled processes, meaning the ability to changeover between central and autonomous control (Fig. 4).
The possibility of switching between central and autonomous control appears advantageous if process deviations (e.g. delayed arrivals of car vessels, prolonged storing processes, delayed process starts within technical treatment, etc.) endanger the globally given delivery dates within the supply chain. Here, a complete rescheduling necessary in these situations is complex and often NP-hard. In contrast, a changeover from autonomously controlled processes to centrally controlled processes appears advantageous if perturbations are mitigated and externally given delivery dates need to be met. Furthermore, this allows more transparency for the employees about the system's status. Hence, they can take action according to the system's situation based on their expertise. Besides, changing over from autonomously to centrally controlled processes can also be advantageous, because a very high degree of autonomously controlled processes can result in a reduced achievement of logistics objectives [8].

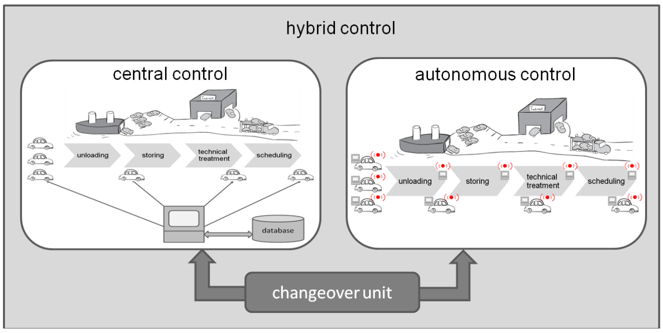

**Fig. 4: Hybrid control of LSP processes.**

The described processes require information close to real time. The generation of relevant information is realized via RFID-equipment and prototypically implemented within the project RAN. However, not all relevant information can be gathered by RFID, e.g. out of order of technical treatment stations, storage areas and the damage of ordered vehicles caused by weather. These may cause a change between both control approaches.
Within the presented research project the changing over between both control approaches is going to be investigated in detail. Especially their impact on the achievement of logistics objectives will be investigated and compared to purely central and autonomous controlled processes. Here, the research will focus on the design of an appropriate changeover control unit (Fig. 4) to switch between the central and the autonomous control approach.
First of all, based on the example of automotive logistics, it is necessary to work out requirements for the hybrid control approach. After this, logistics objectives (e.g. lead-time, inventory, adherence to delivery dates, etc.) are going to be defined, which have to be monitored later on. Based on this, the development of alternative control strategies will follow. In detail, changeover rules from the one to the other control approach have to be developed. Thereby, the control can be changed over for every vehicle or just for the vehicles, which start processing on the automobile terminal after starting changing over. After defining the requirements and control strategies, it follows an implementation of the hybrid control approach in a discrete-event simulation model to test and to evaluate this approach.

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## 5 Conclusion

Due to the increasing complexity and dynamics within production and logistics networks, the application of conventional centralized control approaches turns out to be often not manageable. Within the Collaborative Research Centre 637 autonomous control was suggested to cope with these conditions. However, both, the central and the autonomous control approach have different advantages and disadvantages. Here, a hybrid control approach promises to combine the advantages of both approaches. Within this paper, a hybrid control approach for automotive logistics was presented. This concept of hybrid control will be specified and investigated in its impact on the achievement of logistics objectives compared to central and autonomous control.

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