Published in: Hülsmann, M.; Windt, K. (eds.): Understanding Autonomous Cooperation and Control in Logistics – The Impact on Management, Information and Communication and Material Flow. Springer, Berlin, 2007, pp. 351-363.

4.5 Autonomously Controlled Storage Allocation on an Automobile Terminal

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4.5.1 Introduction

Today, planning and control of logistic processes on automobile terminals are generally executed by centralised logistics systems, which in many cases cannot cope with the high requirements for flexible order processing due to increasing dynamics and complexity. The main business processes on automobile terminals – notification of vehicles by automobile manufacturer, transport to automobile terminal, storage and technical treatment as well as delivery to automobile dealer – are planned and controlled by a central application software system. By establishing autonomous control, vehicles are enabled to render decisions on their own and according to this determine their way through a logistics network on the basis of an own system of objectives.

The idea of autonomous control is to develop decentralised and heterarchical planning and controlling methods in contrast to existing central and hierarchical aligned planning and controlling approaches (Scholz-Reiter et al. 2006). Decision functions are shifted to logistic objects. In the context of autonomous control logistic objects are defined as material items (e.g. vehicles, storage areas) or immaterial items (e.g. customer orders) of a networked logistic system, which have the ability to interact with other logistic objects of the considered system. Autonomous logistic objects are able to act independently according to their own objectives and navigate through the logistic network themselves (Windt et al. 2006). Figure 4.19 illustrates the described paradigm shift in logistics from conventional control to autonomous control.

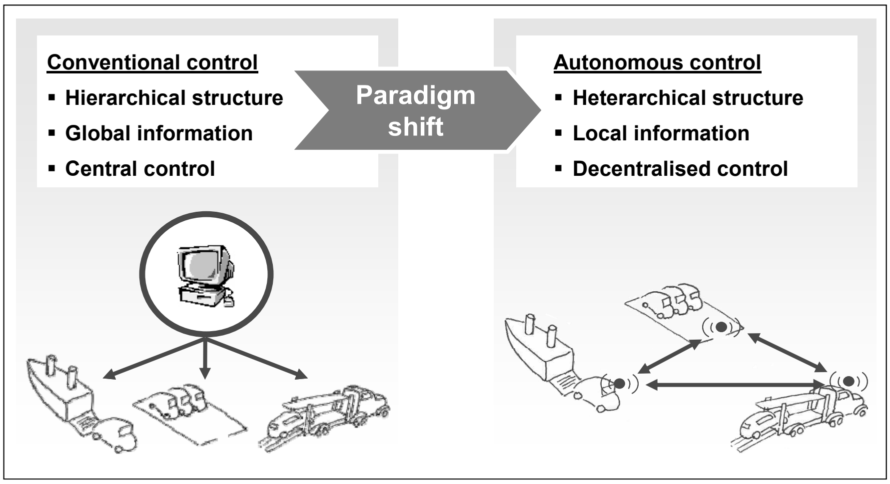

Fig. 4.19 Paradigm shift from conventional control to autonomous control

An essential condition of autonomous control is a high degree of interoperability. Autonomous logistic objects must be able to communicate with other objects and exchange data, in order to ensure the availability of all relevant data needed for decision-making. Recent developments by information and communication technologies (ICT) are of particular importance concerning the fulfilment of this fundamental requirement, including RFID (Radio Frequency Identification) for identification, GPS (Global Positioning System) for positioning or UMTS (Universal Mobile Telecommunications System) and WLAN (Wireless Local Area Network) for communication tasks (Böse et al. 2005; Böse and Lampe 2005).

In the context of this article a new approach of an autonomously controlled logistics system is investigated using as example the vehicle movement processes on the E.H.Harms Auto-Terminal-Hamburg. Several opportunities for improvement by implementing autonomously controlled logistic processes are identified and investigated by means of a simulation study. This case study is a result of the cooperation project “Autonomous Control in Automobile Logistics” between the company E.H.Harms GmbH & Co. KG Automobile-Logistics and the University of Bremen. This research is funded by the German Research Foundation (DFG) as the Collaborative Research Centre 637 “Autonomous Cooperating Logistic Processes - A Paradigm Shift and its Limitations” (SFB 637) at the University of Bremen (Scholz-Reiter et al. 2004).

4.5.2 Initial situation

E.H. Harms develops and provides complex services for new and used vehicles in the range of transport, handling, technical treatment and storage. The group of companies, consisting of E.H.H. Automobile Transports, E.H.H. Auto-Terminals and E.H.H. Car Shipping, has established a Europe-wide logistics network on the basis of automobile terminals at strategically important traffic junctions. Every vehicle passes a set of process steps in the automobile logistics network: collection of vehicles at automobile manufacturer, multi-modal transport to automobile terminal via road, rail or inland waterway/sea, storage and technical treatment as well as delivery to automobile dealer. This article focuses on the logistics order processing of the E.H.Harms Auto-Terminal-Hamburg (EHH Auto-Terminal). The vehicle movement processes of an automobile terminal are illustrated in figure 4.20

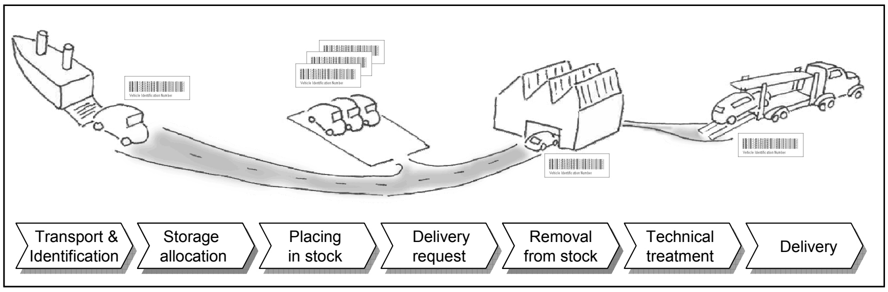

Fig. 4.20 Vehicle movement processes of an automobile terminal

After delivery each vehicle is identified by its vehicle identification number (VIN) from the terminal staff using mobile data entry devices (MDE) which can read barcodes placed inside the vehicle behind the windscreen. The VIN allows an assignment of the vehicle to its storage and technical treatment orders stored in the logistic IT-system. Based on predefined priorities the IT-system allocates a storage location of a storage area to each vehicle. A handling employee moves the vehicle to the assigned storage location. After removal from stock the vehicles possibly run through several technical treatment stations as fuel station or car wash. The sequence of the technical treatment stations is specified in the technical treatment order of the vehicle. Upon completion of all technical treatment tasks the vehicle is provided on the shipment area for transportation to the automobile dealer (Böse et al. 2006).

4.5.3 Opportunities for improvement

The vehicle movement processes on the automobile terminal provide many opportunities for improvement (Böse et al. 2005; Fischer 2004). In particular they result from the centralised storage allocation which is illustrated in figure 4.21 with the Business Process Modelling Notation (BPMN) (Owen and Raj 2003).

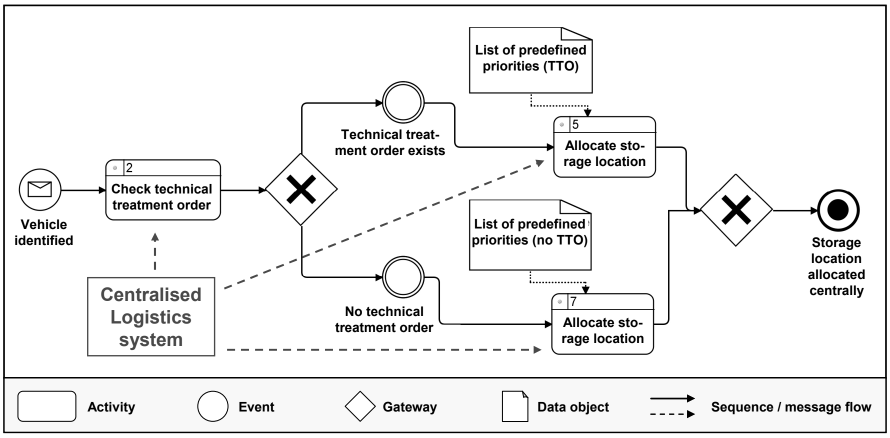

Fig. 4.21 Centralised storage allocation based on predefined priorities

Each vehicle is allocated to a storage location in a storage area on the basis of fixed and predefined priorities. Even though these priorities consider if there are possible technical treatment orders assigned to the vehicles, there is no differentiation regarding the type of technical treatment and therewith the location of the technical treatment stations which are partially a long way away from each other. As a result of the fix prioritization of the storage areas for vehicles with or without technical treatment orders, a flexible selection of storage areas in consideration of future process steps is not possible. Furthermore, the parking time – meaning the time of a vehicle in a storage area to be parked by a handling employee at a designated storage location - is not taken into account in the scope of the storage allocation process. This is of particular importance due to the fact that the needed parking times of storage areas can heavily differ depending on their stock level. As a result time saved due to the short distance between current vehicle location and selected storage area is possibly compensated by a long parking time in the storage area.

4.5.4 Objective target

To realize the opportunities for improvement concerning the storage allocation and the related vehicle movement processes described above, a decentralised decision-making approach for autonomously controlled logistics systems is developed. According to the definition of autonomous control, autonomous logistic objects are enabled to process information, render and execute decisions on their own (Böse and Windt 2007). In consequence, both the vehicles and the storage areas have their own master data and act independently regarding their local objective system (compare figure 4.22).

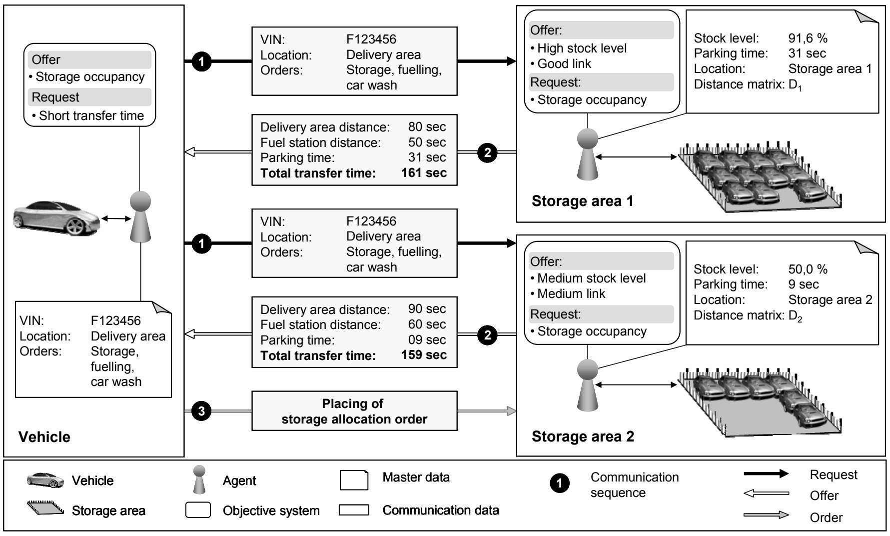

Fig. 4.22 Autonomously controlled decision-making of vehicles and storage areas

Each vehicle has the objective of short transfer times on the terminal area and provides every single storage area the occupancy of a storage location. On the other hand, the objective of the storage areas is high storage occupancy. They offer the inquiring vehicle the total transfer time which consists of the transfer time from the current vehicle location to the storage area, the parking time on the storage area as well as the future transfer time of the vehicle to the first technical treatment station after removal from stock. Depending on the stock level and the position of the storage areas in the automobile terminal, the storage areas can offer a more or less convenient storage time and link to the next technical treatment station. The belonging times described above are added to the total transfer time and transmitted to the inquiring vehicle that compares the received total transfer times of all storage areas and chooses the best-rated. Based on this autonomously controlled decision-making approach, the underlying process chain of the decentralised storage allocation by vehicles and storage areas acting as autonomous logistic objects is illustrated in figure 4.23.

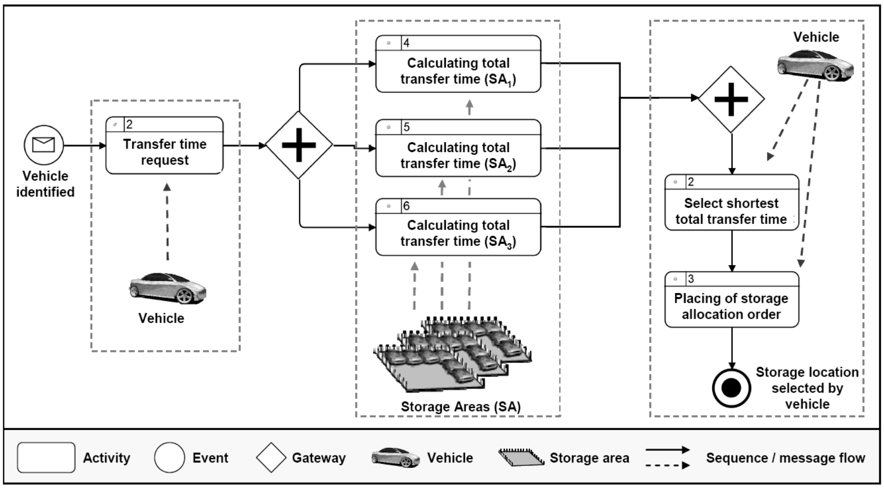

Fig. 4.23 Decentralised storage allocation of autonomous logistic objects

The implementation of such an autonomously controlled logistics scenario of an automobile terminal is already feasible with today's information and communication technologies. The vehicles can be fitted with passive read/write transponders containing the relevant vehicle data as well as the belonging technical treatment orders. The initial data storage on the transponder can be effected by means of a MDE reading an existing barcode and forwarding the information onto the transponder. For this purpose each handling employee is provided with an MDE with integrated transponder reader which enables reading and storing of relevant data on the tags. Furthermore, the MDE contains a communication module based on WLAN that allows the data exchange of the vehicle with other autonomous logistic objects, especially the storage areas, a GPS localisation module for vehicle positioning as well as a user interface. Based on this technological equipment, the process chain of vehicle storage allocation can be described as follows.

After reading the vehicle and technical treatment order data from the transponder placed inside the vehicle a logistic planning and control software system on the MDE determines the best-rated storage area. After that, the handling employee moves the vehicle to the designated storage area and parks the automobile on the fastest reachable storage location (chaotic stock keeping). The MDE in place of the vehicle determines its position on the storage area via satellite using the GPS module and communicates the current storage location to the storage area. Because every vehicle is moved by a handling employee fitted with an MDE, the storage locations of all vehicles on the automobile terminal are always available. As a consequence each storage area has real time information on its stock level at any time. In the following the introduced decentralised decision-making approach for the autonomously controlled storage allocation of an automobile terminal is evaluated by means of a simulation study.

4.5.5 Simulation model

The object of investigation of the simulation study is the transfer times of the vehicles on the automobile terminal. The total transfer time of a vehicle on an automobile terminal TT_{total} consists of the transfer time from the delivery area to the storage location $TT_{storage}$, the transfer time to the technical treatment stations $TT_{technical\ treatment}$ as well as the transfer time from the storage location, respectively the current technical treatment station to the shipment area $TT_{disposition}$ (see Eq. 4.10).

$$TT_{\text{total}} = TT_{\text{storage}} + TT_{\text{technical treatment}} + TT_{\text{disposition}} \tag{4.10}$$

The transfer time from the delivery area to the storage location $TT_{storage}$ is divided into the transfer time from the delivery area to the storage area $TT_{storage\ area}$ and the parking time on the storage area $TT_{storage\ location}$ (see Eq. 4.11).

$$TT_{\text{storage}} = TT_{\text{storage area}} + TT_{\text{storage location}} \tag{4.11}$$

The transfer time to the technical treatment stations $TT_{technical\ treatment}$ is composed of the variable transfer time from the storage area to the first technical treatment station after removal from stock $TT_{technical\ treatment,\ variable}$ and the fixed transfer time between the technical treatment stations $TT_{technical\ treatment,\ fixed}$ (see Eq. 4.12).

$$TT_{\text{technical treatment}} = TT_{\text{technical treatment, variable}} + TT_{\text{technical treatment, fixed}} \tag{4.12}$$

Finally, the transfer time from the storage location, respectively the current technical treatment station to the shipment area $TT_{disposition}$ consists of the variable transfer time from the storage area to the shipment area $TT_{disposition, variable}$ and the fixed transfer time form the last technical treatment station to the shipment area $TT_{disposition, fixed}$ (see Eq. 4.13).

$$TT_{\text{disposition}} = TT_{\text{disposition, variable}} + TT_{\text{disposition, fixed}} \tag{4.13}$$

The transfer times described above show both fixed and variable time slices. For example, the transfer time of a vehicle between technical treatment stations is fixed because of the predetermined handling sequence in technical order processing. For instance, a vehicle is always moved to the car wash after executing technical services or installations in workshops. A variable time slice is the transfer time of a vehicle from the storage area to the shipping area because this time slice depends on the previously made decision regarding the storage area. Recapitulating, only such vehicle movement processes contain opportunities for improvement regarding the total transfer time which have a variable starting or end point. In the considered example these are the vehicle movement processes from or to the selected storage area in the context of placing in or removal from storage. Each vehicle can determine the best possible storage location and minimize its total transfer time on the automobile terminal area considering the distance between delivery area and storage areas, the stock levels of the storage areas as well as the first destination after removal from storage.

The basis of the simulation study is real vehicle and technical treatment order data of 124.000 vehicles of the EHH Auto-Terminal for the time period of one year. In addition to the delivery area the simulation model includes seven storage areas with an average of 1500 storage locations, nine technical treatment stations with belonging buffers as well as the shipping area. The distances between the technical treatment stations and the several areas of the automobile terminal are represented in a transportation time matrix which contains the transfer times of a vehicle between all considered locations. Based on the described business processes of the conventionally controlled as well as the autonomously controlled storage allocation, two simulation scenarios are developed as follows:

Conventionally controlled Scenario S_C

The storage allocation is executed centralised on the basis of fixed and predefined rules which contain an order of priority of all storage areas for both vehicles with and without assigned technical treatment orders. Depending on the existence of a technical treatment order, each vehicle is assigned to the consecutively next available storage location on the currently prioritised storage location.

Autonomously controlled scenario S_A
The storage allocation is executed decentralised by the autonomous logistics objects. Each vehicle chooses that storage area which offers the shortest total transfer time. Placing in storage is accomplished chaotically, i.e., the handling employee moves the vehicle to the designated storage area and parks the automobile on the fastest reachable storage location.

Based on these simulation scenarios two simulation models are developed and investigated by means of the simulation tool eM-Plant. Figure 4.24 illustrates the implementation of the autonomously controlled simulation model in eM-Plant.

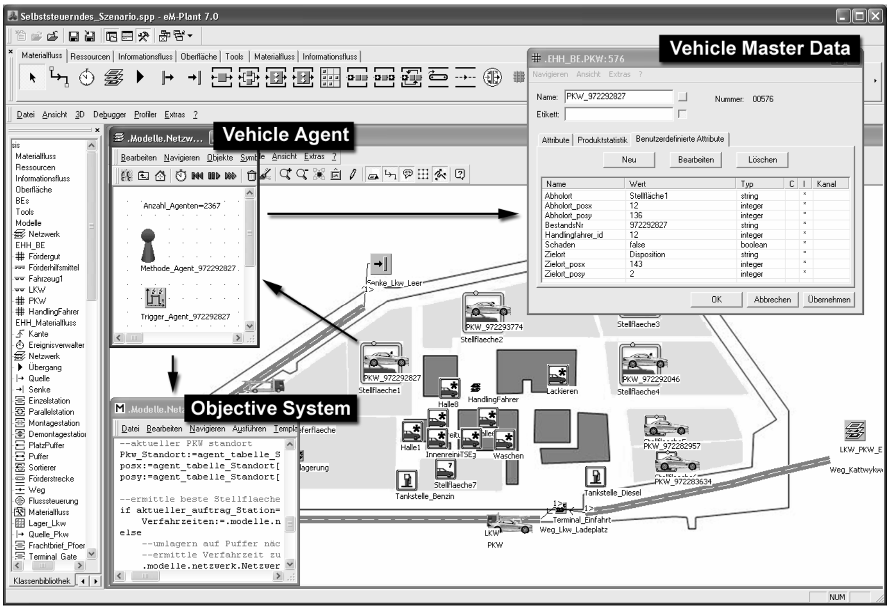

Fig. 4.24 Simulation model of the autonomously controlled scenario S_A

In this simulation model each autonomous logistic object is represented by a virtual agent, for example a vehicle agent. According to multi-agent systems (Ferber 1999) the vehicle agent has its own master data, which are stored in tables. The objective system and the decision functions for planning and control of the vehicle movement processes on the automobile terminal are described in the form of knowledge-based methods.

4.5.6 Results

The main results of the simulation runs are illustrated in figure 4.25 At first the frequencies of the total transfer times per vehicle TT_{total} of the conventionally controlled scenario S_C as well as the autonomously controlled scenario S_A are drawn in respectively one histogram. For the purpose of comparability of these simulation scenarios a continuous frequency distribution is deviated by approximation (compare at the top of figure 4.25).

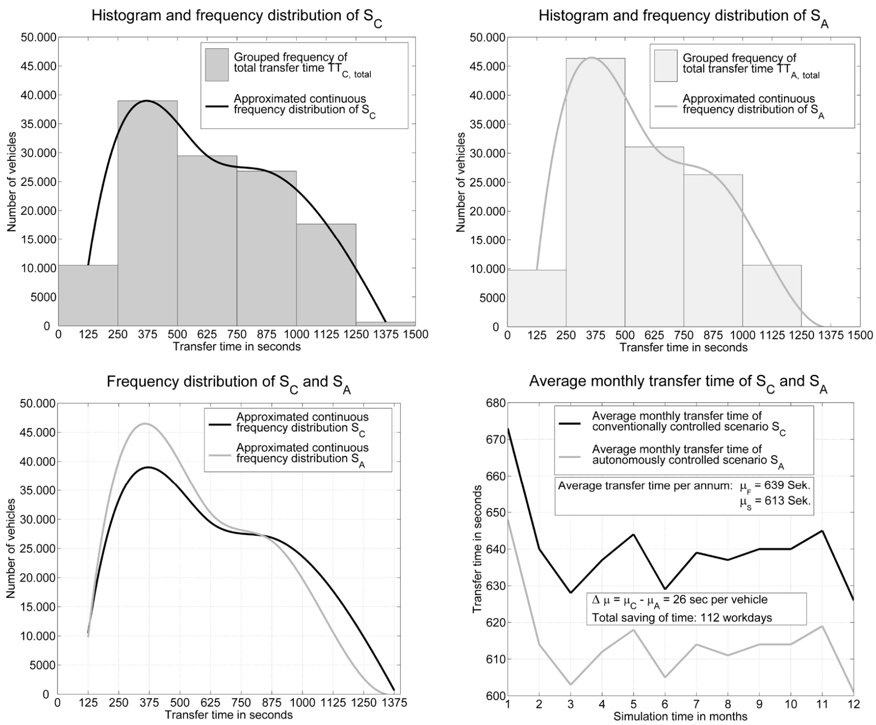

Fig. 4.25 Results of the simulation study

Merging the two frequencies a significant upsetting of the curve of the autonomously controlled scenario becomes apparent compared to the conventionally controlled scenario. In the autonomously controlled scenario S_A more vehicles show a lower total transfer time and fewer vehicles a higher total transfer time than in the conventionally controlled scenario S_C (compare figure 4.25 in the lower left corner). Due to the fact that the data pool of both simulation scenarios is identical regarding the number of considered vehicles, the continuous frequency distributions have an intersection. The average monthly transfer time of the conventionally controlled scenario S_C and the autonomously controlled scenario S_A are represented in the lower right corner of figure 4.25. Both scenarios show a similar behaviour of the curve, but the curve of the autonomously controlled scenario is shifted down. As a consequence, S_A has a lower average monthly transfer time than S_C. The distance between the curves varies depending on the stock level of the storage areas. The higher the stock levels of the storage areas the longer the parking times in the case of chaotic stock keeping and the lower the time saving of the autonomously controlled scenario. The high total transfer times in January result from a large initial stock of the storage areas. The variation of the curve behaviour throughout the year depends on the variable number of moved vehicles and the amount of technical treatment orders. Over the year the average time saving of the autonomously controlled scenario S_A adds up to 26 seconds per vehicle compared to the conventionally controlled scenario S_C. Over all vehicles a total time saving of 112 workdays arises for the vehicle movement processes on the automobile terminal.

4.5.7 Conclusions and outlook

In the context of this article a new approach of an autonomously controlled logistics system was introduced considering as example the storage allocation processes on the E.H.Harms Auto-Terminal Hamburg. As a main result of the presented simulation study the new paradigm of autonomous control in logistics provides significant opportunities of time saving in the field of vehicle movement on automobile terminals.

Due to the fact that the simulation study was strongly focussed on the storage allocation process as a single part of the vehicle management process chain of automobile terminals, further research is directed to the enlargement of the considered application scenario as follows:

- **Consideration of other business processes**
  In addition to the vehicle movement processes other important business processes of logistic order processing of an automobile terminal are included, for example order sequencing of technical treatment stations.
- **Including new autonomous logistic objects**
  In conjunction with additionally considered business processes exemplary mentioned before, new autonomous logistic objects are included

in the simulation model, for example technical treatment stations, shuttle busses or orders.

- **Adding new logistic objectives**
  Like the vehicles and storage areas, the new autonomous logistic objects posses own master data and an own objective system. Therefore it is necessary to add new logistic objectives. Technical treatment stations for instance aim for the goal high utilization while orders have the objective high due date punctuality.
- **Investigation of disturbances**
  To verify the thesis that the allocation of planning and control tasks to autonomously controlled logistic objects effects a higher achievement of logistic objectives because of a better coping with high dynamics and complexity in today's logistics systems, several disturbances are added to the simulation model (e.g. break down of technical treatment stations or rush orders).

The main objectives of these enlargements of the simulation scenario are both to investigate and evaluate other fields of application of autonomous control in the context of logistic order processing of an automobile terminal and to emphasize the significant advantages of autonomous control like better coping with complexity and dynamics as well as higher flexibility and robustness of logistics systems.

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