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INTEGRATION ASPECTS OF AUTONOMOUS CONTROL IN EVENT LOGISTICS

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Abstract The disposition of rental articles constitutes a complex logistic problem. In general, those articles circulate in closed logistic systems and their order-oriented transport between different hubs within the network defines a variety of the Traveling-Salesman-Problem (TSP). As the complexity of this problem class grows with the number of parameters involved, resolving the TSP is a challenging task in daily business. This is especially the case in the field of event logistics, a business area, which extends the common problems related to rental articles with a dynamically changing logistic system. This paper addresses the application of methods from the field of autonomous control for the disposition of rental articles in event logistics with a special focus on the integration aspects. As information transparency is an indispensable requirement for the application of autonomous control, the provision of the corresponding hardware for identification, positioning and communication purposes is the first emphasis. The second is the design and integration of the related agent-based disposition software within the typical software landscape of a company. A small enterprise from the relevant business field serves as an example for the integration proceeding.

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1. INTRODUCTION

The efficient allocation of resources within production and/or logistic networks is a well-known problem (Hodge & Glazebrook, 2011). If the resources are completely or partially reusable, the complexity further increases (Huth & Mattfeld, 2008). In many application cases, the allocation problem comes along with other problems, such as the pick-up and delivery problem. In the following, the complex of time and restriction dependent allocation of resources is subsumed as scheduling.

The disposition of rental articles in closed logistic systems, for example, is one of these cases. Comparable to other re-usable resources, such as containers or trailers, rental articles do not finally remain at the customer, but stay for a certain period of usage before they return to the lender (Kuo, 2011). Depending on the type of articles, the delivery, retraction and possible intermediate processes require a complex and dynamic scheduling (Andreev, et al., 2009). A typical use case is the car rental business. Customers choose a certain kind of car and specify the time and place to pick it up and to drop it. The rental company has to assign a driver, who delivers the car and leads it back after the return. In between, the driver may need a transfer back to the station or the next car, has to wash a car and so on. Further, technical processes, such as repairs, maintenances or refuelling require an additional harmonization (Andreev, et al., 2009).

The presence of diverse customer interests and key figures (costs, distance, etc.) with corresponding interdependencies requires a combined planning and scheduling. As central planning approaches are often not able to handle dynamic and complex scenarios efficiently, other methods came into focus (Argoneto, et al., 2008). The application of new concepts, such as the paradigm of autonomous control, in combination with modern information and communication technologies (ICT) offer the possibility to develop new decentralised approaches.

This paper presents a scheduling approach for rental articles in closed logistic systems following the principles of autonomous control. The approach comprises a multi-agent based simulation system that is responsible for an adaptive, flexible and decentralised decision-making. Main focus of the presented work is the integration of the software system and the required hardware for information acquisition in the processes of an example company from the field of event logistics. The structure of the paper subsequent of this introduction is as follows. Section 2 introduces the business area of event logistics, outlines the problems of the use case as well as the current system architecture and finally summarises related relevant literature. Section 3 describes the scheduling approach and the related software and hardware parts, while section 4 deals with the integration proceeding. The paper closes with a summary and an outlook on future work in section 5.

2. DECISION SITUATION

System integration can be described as the combination of different parts or subsystems in order to obtain a greater system. In general, the objective is to use the individual properties of the subsystems for a joint objective. At this, the margin reaches from the construction of new electronic devices (Wijesundara & Azevedo, 2011) over the evolution of existing systems up to the fusion of specialised systems in the context of a company merger (Li & Su, 2001).

Within the presented paper, the focus lies on the integration of a new scheduling system consisting of software and hardware into the processes of an event logistics company. As a careful analysis of the initial situation and a corresponding adaption of the system is an indispensable precondition of the integration, the following subsections describe both the addressed business area and the concrete use case in detail.

2.1. Event Logistics

The logistic services related to the accomplishment of events, such as company anniversaries, concerts or public rallies, can be subsumed under the term event logistics (Harjes & Scholz-Reiter, 2012) and further be understood as a sub-process of event management. At this, event management means the organisational tasks, including the artistic arrangement (Allen, et al., 2010).

In general, the logistic part of event accomplishment comprises the transport of event specific equipment, such as chairs, tables, benches, cloak hangers, catering supplies or technical equipment (Holzbaur, et al., 2005). Further, the services include the setup and deconstruction of the equipment at the venues. Due to the heterogeneous composition of the loadings, high customer requirements and dynamic occurrences, the related scheduling processes have a very complex character.

In combination with the route planning, event logistics covers two scientific problems: the event-oriented scheduling problem (Gudehus, 2012) and a multiple vehicle pick-up and delivery problem with time windows (PDPTW) (Parragh, et al., 2008). In the presented scenario, the latter involves multiple vehicles, time windows, an incomplete list of destinations at the departure and restrictions of the transport capacity (Harjes & Scholz-Reiter, 2012). Therefore, it can be seen as a vehicle routing problem (VRP) (Parragh, et al., 2008).

2.2. Use Case

In this paper, the logistic processes of a full-service agency from the field of event marketing act as an example scenario. The considered company has 60 employees and mostly operates from its central storage directly at the company headquarters. The offered services comprise the complete organisation of events, including the artistic part as well as the letting of equipment and personnel.

The related scheduling and transport processes underlie high customer requirements regarding the flexibility, cost-effectiveness and technical reliability (Harjes & Scholz-Reiter, 2012). Further, dynamic influences, such as defects, thefts or rush orders complicate the daily business. Currently, the planning follows a centralised proceeding. It mostly bases on an ERP-system (Enterprise Resource Planning) that possesses additional modules for accounting and project-documentation purposes. The allocation of resources takes place in a project-oriented manner. At this, a project manager allocates the related equipment, personnel and the required transport vehicles manually, basing on his personal expert knowledge. The data entry also resides with the project manager.

This approach often leads to an inefficient utilisation of the involved resources due to a comparatively slow adaption to changing parameters. If orders change or new orders arrive, the required replanning causes a high effort. It is further very time-consuming. Altogether, the planning processes and the planning results are insufficient. Besides the slow adaption to changing boundary conditions, a lack of transparent and actual planning data further complicates the event accomplishment.

In general, the material flow takes place between the central storage and one or more venues. In the simplest case, a set of equipment leaves the storage only for one event before it returns. In contrast, the typical use case comprises a series of events at different venues. An automatic documentation of the loading processes only takes place at the storage`s exit via RFID (Radio Frequency Identification). Goods movements direct at the venues often stay undocumented. In some cases, the involved personnel write paper-based lists, use MDE-devices (Mobile Data Entry) or call the project manager via telephone.

This leads to a non-transparent information situation with regard to the position, condition and availability of resources. Therefore, a decentralised order picking for the subsequent event is often complicated. Summarised, the current centralised planning approach is often inefficient in the case of dynamic disturbances and further lacks actual planning data from the different venues.

2.3. Current System Architecture

The current system architecture of the example company consists of an ERP-system on the software side and an RFID-based system for logistic-related data acquisition on the hardware side. The ERP-system comes into operation for the management of inventory data as well as for project-planning and accounting purposes. At this, every event constitutes a project with related resources, such as assigned personnel, vehicles and equipment. The resource allocation bases on the inventory data from the central storage, the assignment takes place manually by the project manager.

The underlying data is stored in SQL-Databases (Structured Query Language) consisting of the inventory data as well as project and customer related information. The current distribution of the inventory constitutes an approximated value, as several aspects are not gathered regularly. For example, the unavailability of equipment or vehicles due to maintenance is often not reported.

The documentation of outgoing goods bases on RFID. Every load carrier or the load itself is equipped with a corresponding tag. An RFID-gate at the warehouse exits reads out those tags and enables a comparison of the cargo list and the corresponding picking list. Further, the database receives an update. In general, an automatic documentation of the loading processes at the venues remains undone (ref. section 2.2). In some cases, load carriers or cargo have an additional barcode. In these cases, MDE-devices, such as barcode scanners, come into operation.

2.4. Relevant Literature

The business area of event logistics touches the problem of scheduling under dynamic circumstances in combination with the vehicle routing problem. As both topics are well known in literature, a large amount of related work exists. Scheduling, for example, covers a wide range of activities related to planning and control activities and is therefore a central point in the field of operations research. At this, the range goes from machine job scheduling (Eiselt & Sandblom, 2012) up to the synchronization of complete supply chains (Herrmann, 2010). The specifics of event logistics require a dynamic and event-oriented scheduling (Gudehus, 2012).

As already mentioned in section 2.1, the routing of transport vehicles between different venues constitutes a vehicle routing problem. In general the VRP is an extended variety of the Travelling Salesman Problem (TSP) (Applegate, et al., 2006). In its basic form, the TSP denotes the search for an optimal route to visit different places exactly once before the return to the origin (Punnen, 2004). The consideration of additional constraints, such as several vehicles (salesmen), time windows and varying numbers of destinations defines a Multiple Online TSP or Vehicle Routing Problem, respectively (Jaillet & Wagner, 2008). The typical situation of the example company corresponds to the VRP with backhauls. This problem class considers a central storage, multiple vehicles and destinations as well as time windows and further environmental restrictions.

The integration of an autonomously controlled scheduling system into the software landscape and the processes of the use case partially follows known approaches from the field of systems engineering. Concepts, such as the v-model, are adaptable for integration purposes (Denno & Feeney, 2002). In general, within the integration process, a definition of requirements and the development of a corresponding system solution take place. The system solution leads to a system concept that constitutes the template for the final system architecture (Denno & Feeney, 2002). The starting point of the integration differs depending on the preconditions and the existing architecture. Often, cost factors lead to an adaption of the new software system to the existing architecture (Land & Crnkovic, 2003). Those architecture-based approaches can address different system levels: code, data and an integration basing on import/export interfaces. While integration on code level is quite expensive and has the highest time effort, the integration via interfaces is relatively fast and economic. In contrast, a code-based integration offers the highest application performance, while an extensive use of import and export functions stands for the opposite (Land & Crnkovic, 2003).

This paper focuses the integration of a system with both hardware and software components. Therefore, the integration proceeding varies with regard to the integration level between the interface level (hardware part) and the data level (software part). The resulting system retains the existing architecture on the one hand, while it extends it with new functions on the other hand. Therefore, it constitutes a variant of the architecture-based approaches (Bass, et al., 2003).

3. THE SCHEDULING APPROACH

3.1. Autonomous Control

The paradigm of autonomous control denotes a decentralised decision-making of autonomous objects in heterogeneous environments (Windt & Hülsmann, 2007). Within autonomously controlled systems, the application of modern information and communication technologies (ICT) enables the single objects to act independently and to follow individual objectives (Böse & Windt, 2007).

Typical and in the most cases indispensable prerequisite for the implementation of autonomous control is the presence of technologies for identification, locating, communication and decision-making. Common are, for example, RFID-systems for identification, GPS-devices (Global Positioning System) for location purposes and UMTS-based devices (Universal Mobile Telecommunications System) for the communication functionality. The decision-making requires a kind of mobile processing unit, such as an embedded system or a small industrial PC (Personal Computer). If the environmental conditions and/or the size of the objects within the system do not allow the attachment of one or all these technologies for every object, different scales of autonomous control are possible. One possibility is the application of fixed installations (RFID-gates, etc.) for the information acquisition and an agent-based representation for the autonomous decision-making (Windt, 2008).

3.2. Agent-based Scheduling

The use case often comprises a rough environment at the venues (open air locations, loadings in a hurry, etc.) and is further characterised by a heterogeneous composition of the event equipment. Therefore, an extensive attachment of ICT-devices is very difficult. As a result, a specialised hardware unit comes into operation for the data acquisition and a multi-agent based system (MAS) takes over the decision-making.

MAS aim at the interactive, coordinated and distributed solving of problems (Ferber, et al., 2004). With regard to the use case, every object within the logistic system has a representing software agent with individual properties, corresponding knowledge and abilities as well as individual objectives. The scheduling of the involved resources personnel, event equipment and transport vehicles is the result of negotiations between the agents. For the simulation, a system called PlaSMA (Platform for Simulation with Multiple Agents) comes into operation. This software focusses especially of the simulation of autonomously controlled systems (Warden, et al., 2010).

In general, the event-oriented scheduling passes through the following steps. The project manager creates a project for every incoming order (event) within the existing ERP-system and assigns a preliminary list of the required equipment. The content of the equipment list depends on the customer`s wishes concerning the artistic arrangement and the venue-specific conditions. The article list is the basis for the agent-based scheduling process.

Within the simulation, every article list has a corresponding agent called list manager. This agent is responsible to allocate the requested resources for the event accomplishment. The determination of the specific articles, employees and transport vehicles results from the negotiations of subsequent agents. Similar to the project related list, every resource has a representing agent. As the example company organises the equipment in article families, every article type has a corresponding ArticleManager. This agent is responsible for all devices of the respective type. For example, the ArticleManager for microphones is responsible for all microphones, while all microphones also have a specific agent, the DeviceManager. Devices that consist of several components, such as a stage, further have agents for the individual components (ComponentManager). The representation of personnel and vehicles within the car pool is similar.

The scheduling process emanates from the ListManager in form of requests for the availability of the required article types. The ArticleManager are responsible for the determination of the specific devices (eg. microphone nr. 6), the DeviceManager again determine the availability of their components, if present. Besides the temporal and technical availability of specific devices, the transport and the corresponding route planning is subject of the negotiations. As the transport vehicles constitute a bottleneck with regard to their capacity and workload, a device can only confirm its participation in the event, when the transport is assured. The scheduling process ends, when all ListManagers of open orders/active events have the confirmation for every required article and the corresponding transport is guaranteed. The final route planning follows the Distributed Logistics Routing Protocol (DLRP). This protocol adapts data routing protocols from decentralised information networks for the routing of autonomous objects in logistic systems (Rekersbrink, et al., 2008).

The final results of a PlaSMA-simulation are the transport routes for the vehicles, the corresponding picking- and cargo lists as well as the personnel planning for the current events. If orders change, new orders arrive or disturbances occur, an additional simulation run with correspondingly adapted parameters realises the required replanning.

3.3. Information Acquisition

The acquisition of the relevant information for the simulation runs relies on the existing RFID-gates at the storage exits and a new additional hardware module for the use within the transport vehicles (Fig. 1). This module is responsible for the documentation of loading processes outside the storage, directly at the venues.

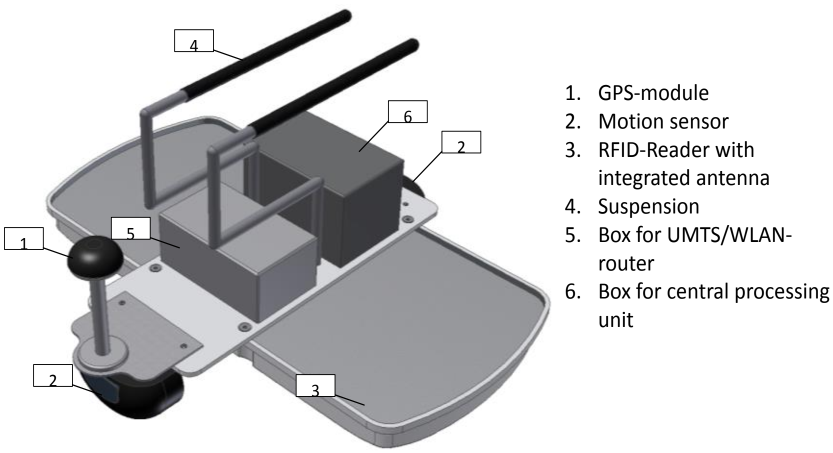

Fig. 1 Hardware module for information acquisition (own depiction)

The module combines an RFID-antenna with integrated reader, a GPS-module, an UMTS-Router, an industrial PC, two motion sensors as well as an integrated energy supply. This combination enables the identification of articles, the distinction of loading and unloading processes as well as the location determination of the vehicle. Further, the industrial PC processes the collected data and coordinates the transmission via the UMTS-router. As the typical place of action for the hardware module is the loading dock of all transport vehicles in use, the module`s design focuses on resilience and applicability in different kinds of vehicles. With regard to the specific car pool of the use case, lorries with a payload of up to 40 tons, medium-sized trucks around 7.5 tons and typical delivery trucks are considered. In order to ensure the employability in rental-vehicles, the design aims to an easy attachment and a non-residue detachment of the unit. The degree of protection against a rough treatment in daily business, splashing water, rain, dirt and dust follows the standard (IP-Code) IP 65 ((ISO), 2006).

4. INTEGRATION PROCEEDING

The integration of the scheduling approach comprises several aspects. The first is the distinction between hardware and software integration. Further, both system parts have procedural and technical aspects.

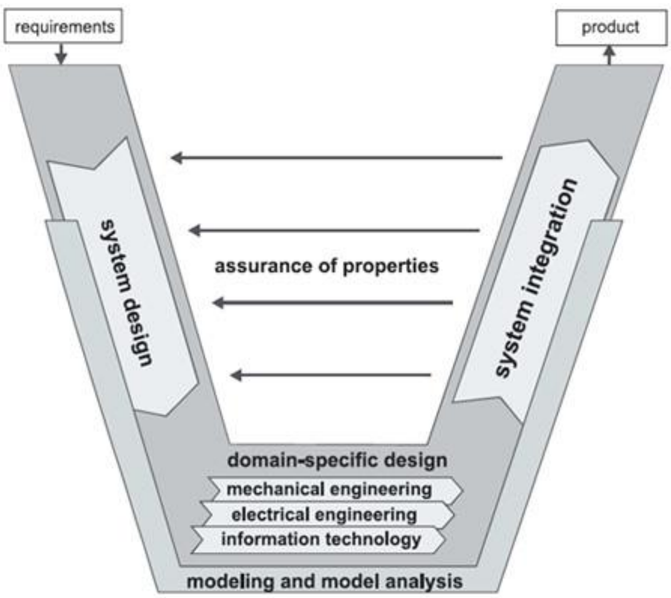

Fig. 2 V-Modell (Boehm, 1979) (VDI, 2004)

As mentioned in section 2.4, several existing system development and integration approaches are applicable for the considered use case. The presented work bases on an adaption of the v-model. This proceeding leads from a system design based on the use case specific requirements over domain-specific sub concepts for the hardware and software part and ends with the integration of the whole system. The correlation between the initially defined requirements, the corresponding system design, the intermediary results and the final product is verified continuously during the process. At this, it largely follows the original conception of Boehm (Boehm, 1979) supplemented with some additional aspects for the parallel integration of hardware and software (VDI, 2004) (VDI, 1993). Figure 2 depicts the general proceeding. The following subsections give a separate overview of the integration process, for hardware and software respectively.

4.1. Hardware Integration

The procedural integration of the hardware units is quite simple. As the unit design aims to a mobile use in different kinds of vehicles, the integration only comprises the installation and detachment at the tail lift. At this, the driver is responsible to attach and activate the unit before eventual loading or unloading processes and to detach it afterwards. During transport, the unit remains in the vehicle´s cargo area.

The technical integration mostly focusses on the regular transmission of the acquired information. At this, the processing unit generates an xml-file that contains the cargo lists with the identified RFID-tags and the corresponding date, time and GPS-position. The transfer of the complete report takes place via the cell phone network. A file server using the File Transfer Protocol (FTP) serves as the interface between the external data acquisition and the internal scheduling system. The server regularly checks the incoming folder for new content and updates the database of the scheduling system, if required.

Naturally, this proceeding especially aims at the use case. If the integration takes place in a company, where the use of rental devices is not required and/or the car pool is already equipped with the relevant telematics, the integration may follow a different proceeding. In general, it is important to detect material movements automatically and to transfer acquired information into the database of the scheduling system.

4.2. Software Integration

The procedural integration of the simulation based scheduling system depends on the structure of the present software landscape. If an existing ERP-system mostly serves for warehouse management and accounting purposes, PlaSMA can take over the majority of the project related tasks. In this case, it is possible to enter the projects directly into PlaSMA`s database. The corresponding GUI (Graphical User Interface), the functionality behind it and the work presented in this paper originate from the same research project (please refer to the acknowledgement). Figure 3 depicts an overview of the functionality in form of a sitemap.

In the case of the example company, the ERP-system possesses additional project related functions. At this, the set-up of projects takes place within the ERP-System directly after the order receipt. The PlaSMA-system intervenes after the artistic planning and imports the project data consisting of place and date of the event as well as the preliminary article list. After the scheduling process, PlaSMA returns the results to the database. Now, it is possible to access the complete resource allocation via the user interface. The drivers for example, obtain their routes, while the warehouse staff gets cargo- and picking lists. Further, the complete personnel planning for the events are available. A partial update of the ERP-database for accounting purposes constitutes the final step of the scheduling process.

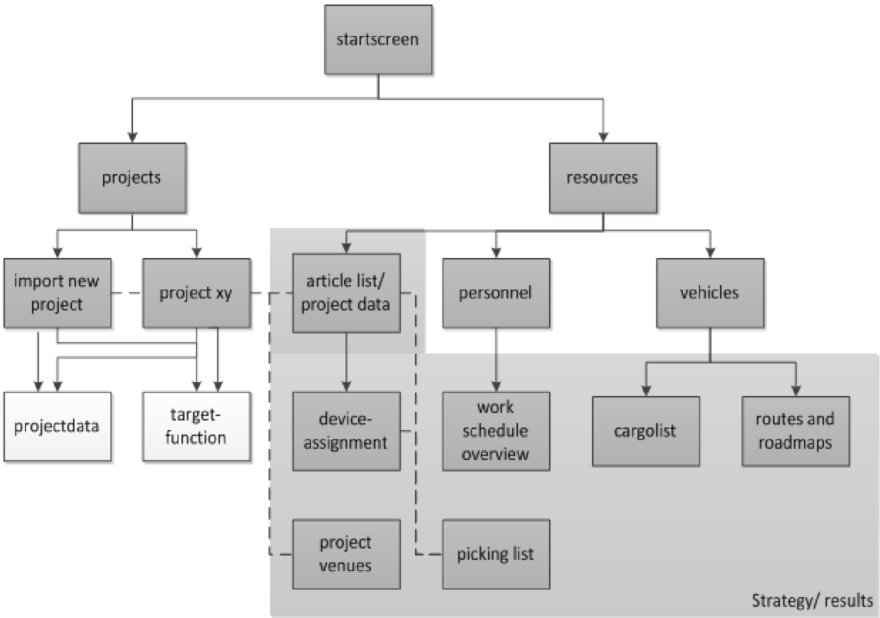

Fig. 3 Sitemap of the graphical user interface for PlaSMA (own depiction)

The technical integration of the scheduling software mostly focusses on the (project-)database. As the database contains data from several sources with regular updates, the integration on data level requires an interface for the data synchronization with the ERP-system. Depending on the kind of the related databases, it is possible to share parts of the database (e.g. individual tables) or to establish a special database for the data exchange. The example company uses an ERP-system that uses an Oracle-SQL database. As PlaSMA also applies an SQL-based approach, the systems are compatible on the data level and can share the relevant parts of their databases.

4.3. System Architecture

The integration of the hardware and software parts of the scheduling systems within the example company results in the overall system architecture in Figure 5. Central point of the resulting architecture is the data exchange between the different software systems. At this, the integration of the on-site data acquisition takes place on interface level.

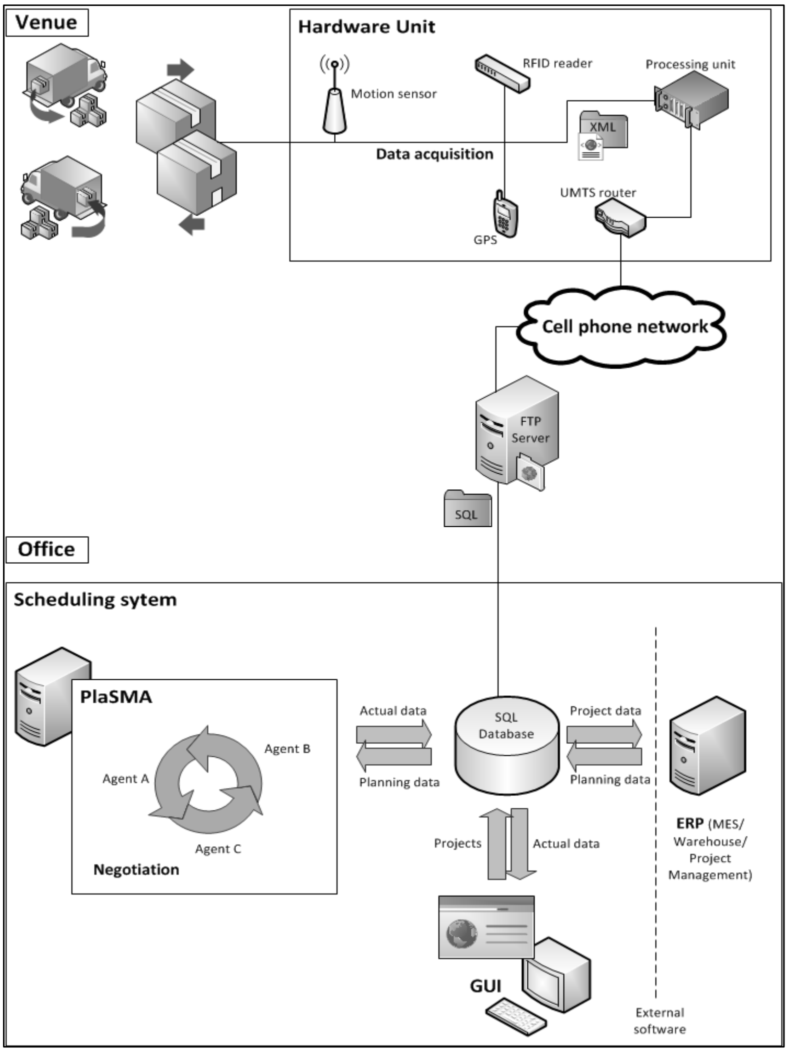

Fig. 4 Overall system architecture

An FTP-server receives a corresponding xml-file via the cellular network and conducts the export into the SQL-database. The exchange between the ERP-system and the PlaSMA-simulation concludes directly on data level, as both systems base upon compatible databases.

Generally, the integration depends on the preconditions of the target company. The presence of suitable telematics within the car pool influences the interface between the planning database and the on-site data acquisition. Further, the design and task allocation of the already present software landscape is from interest. If PlaSMA is responsible for all project related tasks, a data exchange between an external project management and/or enterprise resource planning system may be less extensive or even unnecessary. The design of the data exchange again, if required, depends on the compatibility of the individual databases. If both systems use a completely incompatible database, the integration may take place on interface level, in form of multitude import and export processes in both directions.

5. CONCLUSION

The presented paper deals with the integration of a system for the autonomously controlled allocation of resources in the field of event logistics. The system focuses on the specific challenges related to the distribution of rental articles, transport vehicles and personnel in the above mentioned business area. The paper describes the functionality of the system as well as its software and hardware parts. An example company demonstrates the specifics of event logistics and serves as a use case for the integration proceeding. The presented work closes with a description of the final system architecture, consisting of the previous software and hardware landscape of the example company and the additional system parts of the scheduling system.

From the logistic perspective, future work should focus on the optimisation of the scheduling performance and the quality of the vehicle routing. From the perspective of system integration, the standardisation of interfaces between possible existing software systems, such as ERP-systems or MES (Management Execution Systems) should be from major interest. At this, the data exchange is the central point, as the availability of actual planning data is decisive for the overall system performance and the common database is at the same time the focal point of the system integration.

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Florian Harjes, born in 1981, is a scientific research assistant at the Bremer Institut für Produktion und Logistik GmbH (BIBA) at the University of Bremen. He received a diploma in computer science from the University Bremen in 2008, where he pursued his thesis “Exact synthesis of multiplexor circuits” at the same year. During this time, he developed a tool for the automated synthesis of minimal multiplexor circuits for a corresponding Boolean function. In BIBA, Dipl.-Inf. Florian Harjes is in charge of long time simulations of neural networks and the development of a hybrid architecture for the continuous learning of neural networks in production control. He further investigates the application of autonomous control methods in event logistics.

Bernd Scholz Reiter, born in 1957, studied Industrial Engineering and Management at the Technical University of Berlin. After his doctorate in 1990, he was an IBM World Trade Post Doctoral Fellow in Manufacturing Research until the end of 1991. Subsequently, he worked as a research assistant at the Technical University of Berlin and in 1994 was appointed to the chair of Industrial Information Technology at the Brandenburg Technical University of Cottbus. From 1998 to 2000, he was head of and founder of the Fraunhofer Application Center for Logistics Systems Planning and Information Systems in Cottbus. Since 2000 he heads the chair of Planning and Control of Production Systems in the Department of Manufacturing Engineering at the University of Bremen. At the Bremer Institut für Produktion and Logistik (BIBA), Prof. Scholz-Reiter works in applied and industrial contract research. Since 2013, he is director of the University of Bremen.