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Productivity Evaluation of Autonomous Production Objects

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***Abstract*—The LUPO project's objective is the rapid evaluation of autonomous technologies in production, assembling and logistics in order to make a solid statement about the best mix of centralized and decentralized control in enterprises. For this purpose a hybrid simulator is developed. The hybrid simulator consists of physical work-piece demonstrators and machine-center demonstrators which are equipped with various autonomous communication techniques. Processes can be quickly built, varied, simulated and analyzed by using a modern production management system. At the end of the project it should be possible to receive reliable results on the benefits of autonomous production objects within a week.**

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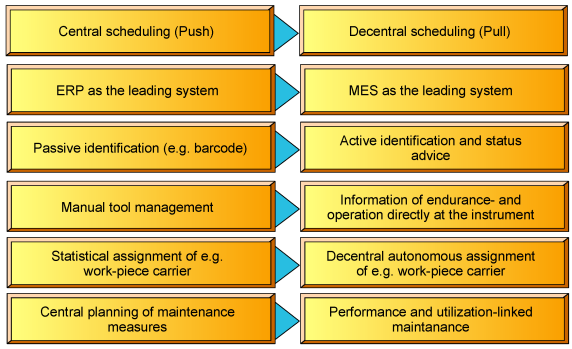

Fig. 1. Components of decentralisation and autonomy in factory

I. Introduction

One of the core skills of the European engine and plant construction is the fast and effective adaption to external as well as internal changes [1]. This might allow for a leading competitive position if the adaption was realized in an acceptable manner by the company itself.

Adaptability enables production systems to change according to the circumstances, such as alternation between in-house and external production, the reorganization of the layouts of production, logistics and assembling, the adjustment to new planning and control methods, changed production network structures (e. g. the establishment of collaborations with new suppliers), decreasing product life cycles as well as fluctuations in demand [2][3]. Autonomous control is a possible approach to cope with these challenges [4][5].

Often, the benefits of autonomous and decentralized technologies can not be identified in the isolated use of single production objects such as work-piece, tools, machine or application system, but in the holistic view, meaning the integrated system with superior and secondary linked information systems, planning and organizational forms. Most projects working on autonomous technologies emphasize the advantages of single technologies. A systematic evaluation and analysis of complex processes and value-added chains is missing. Figure 1 displays the components of decentralization and autonomy in the factory.

Technologies like RFID (radio frequency identification) and Manufacturing Execution Systems enabling decentralized planning already exist but are not used to the extent they should to gain advantages in the competitive position, raising efficiency or profitability of production and assembling. One of the main reasons contributing to this situation is that it is very difficult to figure out the best level of autonomous technologies to gain the best results within a given centralized production system. Thus, the comparision of benefits and additional costs that arise from changing a central into a decentral production control is a complex task.

Hitherto, existing approaches like the experimental research of isolated technologies or the entire computer-based simulation of whole plants usually have a low transferability, a high effort of modeling and linked costs [6]. Additionally a long time-period is necessary until consolidated findings are available. For these reasons they are not adequate for revealing the advantages and costs of autonomous objects of small and medium-sized enterprises, especially in engine and plant construction [7].

In particular medium-sized companies demand efficient real-time solutions to provide integrated manufacturing systems. Efficiency as well as the mutability of the common production system is essential in order to successfully participate in the market affairs [8]. The currently used manual, time-intensive and error-prone production management increasingly does not fit these requirements.

LUPO (LUPO is the abbreviation in German for 'Leistungsfaehigkeitsbeurteilung unabhaengiger Produktionsobjekte' (Productivity evaluation of autonomous production

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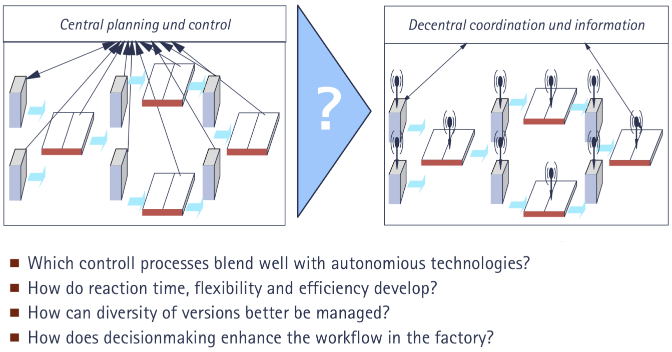

Fig. 2. Research questions of the LUPO projects

objects)) is devoted to companies from mechanical engineering and plant engineering and has three major objectives:

- increasing adaptability
- speeding up the introduction of new products
- increasing the quality of product information

This is done by the rapid evaluation of autonomous technologies in production, assembling and logistics, which includes a grounded statement about the best mix of centralized and decentralized control in enterprises. For this purpose a hybrid simulator is being developed, which provides simulation-based evaluations of computed-action alternatives on the basis of physical demonstrators without disrupting the actual production process. It is funded by the German Federal Ministry of Economics and Technology and realized by the cooperation of the Chair of Business Information Systems and Electronic Government and three medium-sized engine and plant construction companies as well as one manufacturing execution software company. The project's most important research questions are shown in figure 2.

II. Autonomous Technologies

The burgeoning field of autonomous technology is expected to double within the near future. Sensor technologies, robotics and information processing are being applied to business operations of every type. Autonomous technologies are technologies which are able to intelligently and self-reliantly communicate, act and process as well as store information independently of human interaction.

Autonomous technologies are a combination of hardware, operating system, networks and software. They serve the purpose of data acquisition, data processing and data exchange in separate areas. Usually they are not tied to a defined position but may be transferred to various places easily - data can be exchanged via wireless radio interfaces. Autonomous technologies trigger the decentralization of intelligence within a system. Because of decentralized units decisions do not need to be carried out from a central station but directly at the relevant sites [9].

In order to advance the decentralization of intelligence and to achieve multidirectional communication of autonomous objects, standardized basic technology is employed, e.g. RFID, barcode, electronic labeling. In the retail market, logistics- and automotive-industries the first RFID applications are tested and committed; in mechanical and plant engineering industries they are only introduced within singular parts of applications [10][11]. In general, attempts to first adopt RFID in subprocesses, as a means to verify the benefits and profitability, and then to extend the RFID support to the entire process have been made.

The introduction of RFID into subprocesses poses several difficulties for the verification of profitability. Applications directly supported by RFID activities are usually more efficient; for enabling this support additional activities must be defined. Generally, the entire process is less efficient than previously assumed. Without a proper adjustment of the process environment and essential interfaces, no significant improvements with RFID in the entire process will be achieved. As a result, most projects which adhere to this strategy will be stopped and RFID will be declared not useful. Economic benefits will occur only if, in addition to the replacement of barcodes with wireless technologies, the possible process innovation and improvements are identified and implemented.

A market survey questioning manufacturers and system integrators of RFID solutions identifies the lack of global standards and some technical shortcomings in addition to the currently high cost of the systems as weaknesses of the RFID technology. The lack of knowledge of potential users in terms of possibilities and limitations of the technology leads to false expectations and disappointments [12].

Autonomous objects carry out computed actions through sensor-based perception and communication with adjacent objects. The following scenario demonstrates the usage of objects with autonomous technologies in the production-process. The workpiece, or the workpiece carrier, transfers a request to the machines responsible for the next operation. They answer and report their availability to the former instance. Based on the implemented computated-action-algorithm the workpiece chooses a machine and registers [13]. The machine detects that the appropriate tool is not equipped yet. The conversion is induced automatically, e.g. through a multi-tool holder or by notifying a qualified worker.

This procedure stands in contrast to a strictly centrally organized management. This form of control requires that all data are gathered at one central point. This means, all data has to be communicated and transferred. A classification through relevant planning or computed-action does not take place before reaching the central system. This might cause two serious problems: a large amount of data that needs to be transferred and devastating consequences if it fails. While the breakdown of the central system causes a standstill of the whole system, the breakdown of a part of the autonomic realization results only in the failure of a single component. The overall systems remain unaffected.

III. Objectives of the Project

This chapter explains the main objectives of the LUPO project. It will be analysed how autonomous technologies can help to improve production activities.

A. Fast determination of the benefits of autonomous technologies in production, logistics and assembling

With existing methods it is hard to figure out with which technological and financial efforts as well as with the help of which concrete decentralized and autonomous technologies the best results can be achieved [7]. While on the one side it is nearly impossible to figure out the concrete benefit of autonomous technologies, on the other side they cause high investment needs. This situation causes many companies reason to not invest in autonomous technologies. Thereby the risk of falling behind other companies in the market grows. One of the objectives of the LUPO project is to provide consolidated findings of benefits of decentralized and autonomous technologies of concrete production scenarios within a week. Based on these fast evaluations, companies will be enabled to make founded decisions regarding autonomous technologies. With condition-changes appropriate measures can be developed and introduced quickly. Thus the production system will be more adapative. The company is able to measure up to the continous changes in the market.

B. Increase in adaptability

Adaptability is a key factor for a successful participation in the market competition. Permanent and accelerating change requires short-term responses and thus a high degree of flexibility and responsiveness of business. With these adjustments enterprises will gain beneficial results, particularly in cases of sudden change in the environment [14]. Flexibility of production facilities is recognized and accepted as a necessary tendency in order to react to constantly changing market requirements. The modularization of various machines and production lines replaces the centralized architecture of traditional hard-wired control systems. A dynamic regulation without manual intervention is being sought. Effectiveness and efficiency of production processes should be secured permanently.

This requires a careful selection and proper use of information-processing technologies in the production process and thus becomes a factor of success. At the same time IT solutions have to be assessed for cost reasons. The usefulness of an evaluation strategy is determined by its ability to provide comparable statements under pressure and by its qickness.

The LUPO project's aim is to detect which autonomous technologies in which combination help to increase the adaptability and, consequentialy, the competitive position of productive companies in different industries. The main focus is on the analysis of how process elements can quickly be adjusted to new production layouts, organizational forms and market situations with the help of autonomic technology.

C. Production management with autonomous production objects

As many tasks, as well as the contents of production systems, will change if the production system is based on decentralized autonomous production objects, relevant information has to detected. The project will clarify what information is transmitted in a information system and what new management and control concepts productive enterprises using autonomous and decentralized technologies need. Possibilities to maintain transparency in logistic key figures like high capacity utilization, lead time reduction, material availability and internal adherence to delivery dates through autonomous objects are being worked out.

D. Standardization of production relevant communication

The communication of autonomous objects allows for a reduction of complexity as well as for an inclusion of on-site conditions. Intelligent systems with extendable means of storage, communication and sensors facilitate enables self-empowered exchange of information, environmental detection and task-performance [15]. Currently no unified standard concerning the communication of autonomous technologies in manufacturing is established. A plethora of enterprises use their own methods of communication instead. Consequently small enterprises face the problem of having to meet a wide range of conditions. But to still have to possibility to exchange data systematically it is necessary to contrive ways and means to achieve standardization.

IV. The LUPO Simulation Environment

Simulation in the context of manufacturing can turn out to be advantageous. The costs of modeling and simulation are much lower than an analysis of actual objects in a similarly comprehensive manner [16]. Due to the option of either shortening or expanding the dynamic behavior of the process, precise observations and analyses are possible. In addition, the risk of wrong decisions is minimized. The costs of a simulated or virtual mistake are in no relation to a real one [17].

Discrete event-driven simulation has been used to analyse and optimize many types of systems for several decades [18]. More general, simulation tests can be divided into what-if and how-to-archive analysis [19]. What-if-analysis analyzes the model behavior caused by specific modifications of model data. How-to-archive-analysis defines the objectives to be attained that have to be calibrated.

Simulation tools that may be applied to typical operational scenarios like production lines or complex production processes exist already. Examples are FlexSim or SLX. Both of them are general simulation software. This implies a more complex modeling of specific production problems - regarding the configuration of parameter and definition of relevant process variables - than in a specialized environment. The disadvantage of simulation is that it often is a time-consuming method [6].

On the other hand there is the use of model factories. There is no standard or universally agreed definition for the term model factory. Model factories represent concrete production processes in a simplified form under lab conditions. They are mainly used for educational and teaching purposes, for example at the RWTH Aachen or the HTW Berlin. Due to the inflexibility of model factories, the analysis of new ideas and concepts is restricted to cases with similar usage. Being limited to a concrete production process restricts the use to a defined production situation and prevents the implementation of the model into various processes. The evaluation of alternative scenarios is difficult. At many model factories the analyses are done on the basis of one or a small number of products that are really produced. The obtained results subsequently have to be transferred from this special application to other applications. Thus, often special requirements cannot be considered. The LUPO project differs in so far as there is no actual production. Instead, the used artificial products and processing stations are very adaptable. They are able to represent products of any company; individual results can be generated.

The LUPO simulation environment consists of a composition of physical and computer based models. The main components are the work-piece and the machine center demonstrator as well as a transport line that connects the various machine center demonstrators. Every work-piece demonstrator presents a work-piece in a different state. After having passed a machine center demonstrator the state will change according to the process-step the machine center demonstrator presents. The clearness of the simulation environment supports the argumentation in favor of using corresponding technologies.

The mixed hybrid simulation of physical and computer based models has been chosen to create the possibility of a fast and flexible reproduction of production processes. Neither an exclusive physical, nor an exclusive computer based approach can achieve such a fast experimental set-up. Additionally, certain physical effects like field strength, alignment of aerials or detection rate can be analyzed easily.

The hybrid simulation environment is a mixture of computer added simulation and model factory and combines the advantages of both approaches. The disadvantages are minimized or eliminated wherever possible.

A. Construction of work-piece demonstrator

The illustration of the parts to be worked on are displayed as a 2D or 3D model on both sides of the demonstrator. The monitoring display is on the top side of the demonstrator reporting relevant products, processes as well as job information. All of this information is actual at every time during the course of the simulation. This implies that the data continuously changes within a simulation run - a high clarity of information is provided. The apparent disadvantage of not having a physical product is compensated by the high flexibility and variability of the feasible product range.

Fig. 3. Schematic diagram of a work-piece demonstrator

The work-piece demonstrator includes an industrial PC and a communication module. Communication with other parts of the LUPO demonstrator and the report of production data is thereby enabled. The possible associations of various types of technical sensors (e. g. module for tagging RFID) have to be given. The work-piece as well as the machine center demonstrators may have interfaces providing access to industrial buses like CAN-Bus or Profibus and connection to different sensors. Due to the implementation of corresponding algorithms, the integrated industrial PC enables the realization of different levels of independent operation. Figure 3 shows a schematic diagram of a work-piece demonstrator.

B. Construction of machine center demonstrator and transport lines

The machine center demonstrators are build akin to the work-piece demonstrators (see figure 4). They represent the necessary work tools. The work tool is displayed on both sites of the demonstrator on the monitors. On the top side there is the cockpit of the production management. Different key figures can be displayed and supervised. The machine center demonstrators are conceptualized in a way that they are able to contain transport lines. A maximum of two work-piece demonstrators could stay inside at any given time. They present those work-pieces, that are worked on by a particular machine.

The diverse machine center demonstrators are aligned by transport lines. To ensure a high level of flexibility and adaptability to the simulation environment transport, line elements like switch plates, circular shelves as well as entry points and gates are used. Thus diverse factory layouts like sequences, parallelism or repetition can be represented. Out of these basic layouts any real factory layout can be designed.

C. Enlargement by autonomous instruments and carriers

For preparing all relevant objects of production with autonomous skills, instruments and carriers will be designed as well autonomous devices. While the carriers will be designed as plain work-piece demonstrators, the instrument demonstrators are engineered as an insertion to the machine center demonstrators.

D. Installation of information system in factory

For process control of the simulated production processes, it is necessary to use corresponding software tools. Especially a

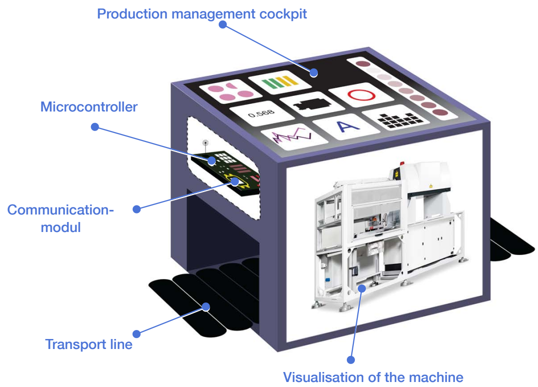

Fig. 4. Schematic diagram of a machine center demonstrator

Manufacturing Execution System (MES) and a related Enterprise Resource Planning (ERP) software is required. Through this combination a realistic construction of those companies that have to be simulated is possible. Like MES, the system of one of the project's cooperation companies is used. The decision in favor of an ERP provider has not been made, yet. The possibility not to use a real ERP System but to use a kind of ERP mockup with those functions that are necessary for the simulation is plausible. An interface need by the MES has to be implemented as well.

E. Implemention of Autonomous Technologies

Computed action by the object itself is a major characteristic of autonomous technologies. Independently, one element of the complete system selects the way how to react to a specific situation within its context. In order to accomplish such a thing the respective algorithms attached to an evaluation of a situation and a selection of appropriate steps of reaction have to be implemented, thereby creating the need to supply the object with inherent processing power. Also, relevant environmental information has to be available as input parameter. Additionally, communication skills are necessary in order to coordinate with the complete system and to gather supplementary information of separate elements of the system. The following performance characteristics of autonomous technologies can be summarized: inherent processing power, sensors or sensor interfaces, as well as the mastery of various communication protocols.

The elements of the simulator hold these performance characteristics. Every demonstrator incorporates one microcontroller. The implementation of computed-action-algorithms (simulation level) and of the control mode of the demonstrator itself (control level) is thus carried out. Interface components enable the installation of various types of sensors and communication modules. Existing technologies may be integrated into the system, e.g. the RFID-reader. Several interface standards are available, established interfaces like Profibus etc. can be utilized. Each demonstrator can be configured for a certain degree of autonomy and can be linked to standard hardware.

V. Cooperation with Industrial Companies

The project is executed in cooperation with four small and medium-sized German enterprises. Three of them are in the producing sector, the fourth is one of the leading providers of manufacturing execution systems in Europe. The manufacturers have heterogeneous manufacturing types: one small-batch production with highly complex parts, one manufacturer of products with variants and one process manufacturer. All of them have quite different objectives concerning the project, but all of them focus on the utilization of autonomous and decentralized technologies to advance their production processs.

Due to heterogeneity, it is possible that the different demands of the manufacturing types can be included and considered during the course of the project. The risk of producing niche technology solutions, which focus on the requirements of single manufacturing types only, is counteracted. Thus the chance to generate generally and highly accepted project results rises. Due to the cooperation with the MES provider it is ensured that all developments, trends and innovations of the MES market are regarded. A professional and pratical orientated discussion of ideas as well as their implementation in a highly-developed software solution is a further advantage.

All companies are integrated into the project from the very beginning. Thus it is ensured that a practical orientation will not be neglected. During the conceptual phase of the simulation environment the needs of the cooperating partners are incorporated and implemented already. This is very significant in regard to the success of the project, because the manufacturers' processes are recreated and analyzed later on in the project. Specifics are considered right from the beginning an subsequent adjustments are no longer necessary. But also in the project's ensueing progression their participation is of the highest importance. According to the companies' objectives, relevant processes are assimilated by cooperation of the companies' employees and members of the LUPO team. Afterwards, these processes are recreated in the hybrid simulation environment. All recreated processes as well as their simulation are being compared with the corresponding real processes. In the case of deviations, adjustments need to be made until an adequate agreement between original and model is achieved. In order to validate the processes it is ensured that the simulated processes correspond to reality as much as possible. The positive side is the transferability of results about the usage of decentralized and autonomous technologies made in the hybrid simulation environment to reality.

VI. Conclusion

By building up a hybrid simulation environment as a mixture of computer aided simulation and model factory, numerous scenarios of production and logistics can be represented and analyzed concerning fields of applications of decentralized and autonomous technologies. The advantages of simulation and model factory are combined. Within a short time period (the goal is one work week) dependable results are achieved. The validation of processes built up in the simulator ensures that the results can be used in practice. The heterogeneity of the partner companies supports the aim not to generate niche but general solutions. The clarity of the simulation environment improves the argumentation in favor of using corresponding technologies. The findings may have far-reaching consequences on the market. On the one hand, the aspired standardization of production relevant to communication obtains a fast and easy communication with various suppliers, customers and systems. On the other hand, the use of the appropriate level of decentralized technologies leads towards a high grade of adaptability and flexibility of the company. This increases the chance of a stable market positioning in the long term.

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