Universität Potsdam
Univ.-Prof. Dr.-Ing. habil. Norbert Gronau
Lehrstuhl für Wirtschaftsinformatik
und Electronic Government
Universität Potsdam
August-Bebel-Str. 89; 14482 Potsdam
Tel. ++49 331/ 977-3322, Fax -3406
http://wi.uni-potsdam.de
E-Mail: ngronau@wi.uni-potsdam.de

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Lass, Sander; Theuer, Hanna; Gronau, Norbert

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A New Approach for Simulation and Modeling of Autonomous Production Processes

Sander Lass
University of Potsdam
slass@wi.uni-potsdam.de

Hanna Theuer
University of Potsdam
htheuer@uni-potsdam.de

Norbert Gronau
University of Potsdam
ngronau@uni-potsdam.de

Abstract

In a world of rapid change, production companies are faced with major challenges. They have to deal quickly to an increase in competition and individual customer requests. New technologies and organizational structures like RFID or decentralized and real-time based production control can handle these challenges. The analysis of a production process and the selection of appropriate technical solutions often proves to be difficult and cost intensive. Previous simulation approaches are frequently combined with high effort in order to state credible propositions regarding suitability and economic efficiency. This paper presents a new opportunity towards overcoming these disadvantages. The approaches of computer-based simulation and model factories are combined into a new simulation approach with reduced effort.

For the purpose of documentation of simulated processes the Value Stream Design method is extended towards the requirements resulting from autonomous production control. For this purpose additional symbolism, data dictionaries and key figures are introduced.

1. Introduction

Taking part in an international competition manufacturers face massive challenges. Quick reaction to constant changing conditions and customer preferences are essential to allow companies to be successful in the market. Due to market dynamics, adaptibility - the ability of a system to identify changing conditions of the environment and to react effectively and efficiently by itself [1] - is a very important characteristic for production companies to remain globally competitive. Especially small and medium-sized manufacturing enterprises (SME) can only gain advantage over their competitors by improving their production processes and reduce their costs.

New approaches and ideas for production management, e.g. autonomous control and the use of new technologies, like AutoID systems - combined with intelligent production systems - offer a solution on how to cope with these challenges. Companies are faced with the task of evaluating both the usage of new technologies and new planning strategies, e.g. decentralized production control in terms of applicability concerning their individual situation.

The demonstration and measurement of economic viability of these alternative systems and ideas towards specific processes in a company often turn out to be difficult. Thus, a complete consideration of processes is indispensable. Focusing just on single aspects often involves the risk of failure. For example the usage of Radio Frequently Identification (RFID) is an approach of developing potenzial in the field of identification. Without the adoption of the process environment and the sub-processes, the process as a whole can not experience major improvements. Due to reasons of high cost the determination of suitability of RFID for a process often starts within an implementation of a small part of the production. An increase in efficiency of the whole process turns out to be insufficient due to the implied conversations in the up- and downstream process steps. Furthermore, the calculated advantages based on this test scenario proves to be inaccurate after the implementation of RFID in the whole process. Therefore many implementation processes are cancelled because applying single sub-ares does not show the desired results. The real potential is not appropriated, thus autonomous technologies are declared as unusable. Especially in SME there is no adequate method for revealing the advantages of autonomous objects [2].

As a result, there is a need for a method that enables resilient statements of the profitability of the usage of autonomous technologies in a quick and cost effective way. A promising approach for such kind of analysis is simulation. According to the Association of German Engineers (VDI) simulation is the "reproduction of a system with its dynamic processes in a model for acquiring knowledge that is transferable to the real world" [3]. Market studies already have shown that the use of simulation offers great potential in different branches with various objectives [4]. Es-

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pecially the creation of transparency in complex decisions, the shortage of planning times as well as an increasing quality and security in planning are highlighted as positive effects [5].

Due to simulating companies' production processes prior and subsequently to the implementation of e.g. autonomous technologies, testing alternatives are carried out without disturbing the actual production processes. In particular, this applies to SME to generate statements about profitability quickly and with less effort.

Nevertheless, different problems arise with the classic alternatives of simulation. Either by merely concentrating on single aspects while the delivered results are not yet sufficient, since they require a high effort of modeling for a holistic view. Because of the necessity of a holistic consideration and caused by an increase in complexity and effort of analysis simulation which normally turns out to be highly cost and time intensive. Therefore new technologies are spread below-average in this area [6]. Most of the existing approaches have a low transferability, a high effort of modeling and linked costs [7]. As a result, the classic variants provide only a limited benefit and their usage for the addressed use case is severely limited.

This article deals with an approach for the reduction of simulation effort of autonomous production processes. It is based on the LUPO project (German appreciation of "Leistungsfähigkeitsbeurteilung unabhängiger Produktionsobjekte" - Productivity Evaluation of Autonomous Production Objects)[1]. The project is realized in cooperation with the university and three medium-sized engine and plant construction companies, as well as one Manufacturing Execution System (MES) company. The LUPO project's aim is to detect which autonomous technologie combination helps to increase the adaptability and, consequentially, the competitive position of production companies in different industries. The main focus is on analysis of how process elements can quickly be adjusted to new production layouts, organizational forms and market situations with the help of autonomic technology [8]. Currently there are prototypes of various parts of the simulation environment.

Section 2 specifies the term Autonomous Control, followed by an introduction of two existing simulation principles, and then discusses their pros and cons. The next section presents a solution for reducing effort of simulation. It describes the procedure model of the LUPO project. Afterwards the modeling-part of simulation of autonomous production processes focuesses on an extension of Value Stream Design for evaluation of profitability. In conclusion a case study which shows an examle of the usage of the simulation environment will follow.

2. Autonomous Control in Production Processes

An essential characteristic of Autonomous Control is decentralized decision-making. There are interacting elements, which possess the capability to make decisions independently. The result is based on environmental data and information gathered from other elements. "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" [9]. Requirements for Autonomous Control are differentiated in information processing, decision-making and decision-execution [10].

Information processing includes data input, data storage and data aggregation. Relevant data has to be tagged to the production object. Therefore special technology is necessary [10]. Examples for such technology are RFID or barcode [11]. Decision making combines the aiming system with predefined rules as well as the communication with further production objects. For the decision execution the communication of different production objects as well as the capability of a production objects to performance alternative processes is necessary [10].

Supplemented by organizational aspects that include strategies of organization and concepts of control, an Autonomous System can be modeled. It has elements that are able to make decisions in an autonomous and decentral way. This would create the opportunity of a production that complies with relevant rules and allows the adoption to changes with a minimum of external intervention. All relevant data are stored, read and evaluated by given algorithms. Based on this, regulations are proceeded [10].

The usage of Autonomous Technologies has high potential. While the common production control uses centralized decision processes, Autonomous Technologies allow storing relevant data on the product itself. This avoids the current separation of the physical product and its belonging information flow. Software systems, like MES, help to realize the decentralized analysis, decision-making and basing control [12].

[1] The project "Leistungsfähigkeitsbeurteilung unabhängiger Produktionsobjekte" (LUPO) is part of the technology programme "Autonomics - Autonomous, simulation-based systems for small and medium-sized enterprises" that is funded by the Federal Ministry of Economics and Technology (BMWi) as part of the IT beacon programme, Internet of Things.

Autonomous Technologies can be separated into centralized and decentralized data storage. In the former case a simple numeric code is tagged on the production objects (data-on-tag). The belonging object oriented data are stored on a central database (data-on-network). At every process, data has to be recalled, updated or submitted. Additionally to the numeric code all object oriented data are tagged directly to the object within the decentralized data storage. Thus, data volume transferred to a central storage and reaction time are reduced [13].

As one of the most common Autonomous Technologies, RFID is mainly used below. The relevance of Autonomous Technologies will increase significantly in the coming years. Nowadays RFID is used in various fields of application. In economy it is mainly used in transportation (31%), production control (18%) and product information (16%) [14]. The RF-ID applications were first tested and used in the retail market, logistics and automotive industries; in mechanical and plant engineering industries they were only introduced in singular parts of applications [15][16].
Reasons for limited distribution of RFID in SME are high initial costs for the technology as well as uncertainty regarding the fulfillment of the objectives [14]. The lack of knowledge of potential users in terms of possibilities and limitations of the technology leads to false expectations and disappointments [17].

3. Analysis of existing simulation approaches

When considering implementation principles of simulation there are mainly two ways of realization namely computer simulation and the use of a physical model. In production processes they are called Digital Factory and Model Factory.

3.1 Digital Factory

Digital Factory is a planning approach, which is used in product development for modeling suitable versions for future objects in order to visualize and perform analysis. The objective is the optimization of product relevant structures, processes and resources [18][19]. Software tools for geometrical representation of setup of all plants as well as simulation systems that map production processes dynamically are in use. Real time monitoring and planning support are connected to one system [20] and establish a shared database for all product relevant software systems.

Modeling a Digital Factory is often costly. Despite decreased costs of IT-systems SME forego the use of this kind of planning. This is mainly in the automotive industry that this planning approach is used successfully [21].

A digital mockup of a product is used to analyze ergonomic issues and functionality, possible construction methods or mere visualization [22]. Above all, the strength of digital mockup lies within shortening of time for product development and design at unchanged costs [23]. An optimization of production processes primarily occurs during product development and focuses on the product itself.

But in the early phases of designing manufacturing processes there is no integrated factory and logistic planning methods that allow a structured comparison of different alternatives based on a set of various criteria [21]. The introduction and use of the different technologies in production process are marginally considered. With regard to the stated aims above, physical systems appear only as data providers.

In summary, a Digital Factory allows simulation without the use of hardware components through digital mockup, that is if there is an adequate implementation of a physical model within the software. Otherwise, it has to be implemented. This possibly causes high effort compared with a hardware variant and results in software tools with high complexity. The strength of digital factories is the product development. With regard to the given objectives digital factories cannot be applied without extending their concepts.

3.2 Model Factory

A model is a simplified variation of a planned or existent system build up to reduce complexity [22]. A Model Factory represents concrete production processes in a simplified way under lab conditions.

There is no standard or universally agreed definition for the term Model Factory and it is mainly used for educational and teaching purposes, for example at the RWTH Aachen or the HTW Berlin. The components in a Model Factory are a physical implementation of their real counterpart and works the same way e.g. machines or production islands. In most cases the specialized model elements have a small field of operations. Their application is limited to similar scenarios.
Due to the inflexibility of model factories, the analysis of new ideas and concepts are restricted to cases with similar usage. The limitation to a concrete production process avoids the use to different production situations and prevents the implementation of the model into various processes. The evaluation of alternative scenarios is difficult. The obtained results

subsequently have to be transferred from this special application to other applications.
Many existing model factories focus on a particular topic or concentrate on a single task. They are developed only as a tool to study and analyze a particular problem, e.g. the project Nexus as part of the collaborative research centre 627 (SFB627) deals with real time tool-management with RFID [24]. The project LEP ("Model Factory for Energy Productivity") - a cooperation of McKinsey and the Technical University Munich – focuses on research in the field of energy cost reduction in production [25]. So far, a solution for a broad range of different problems does not exist.
To sum up, a Model Factory allows a quick realization of physical problems with low effort, but it has a low degree of flexibility concerning different production scenarios. Thus, it is not an adequate solution for the objectives stated in the introduction.

4. Reduction of Simulation Effort

Taking into consideration the already existing simulation approaches, the effort required to gain grounded statements is too expensive because of complex and tedious initial modeling as well as missing flexibility within modification. To improve the usability of simulation in production a suitable starting point is speeding up modeling. A setup of customized simulation environment avoids inflexibility of existing approaches.

4.1 Alternative Approach of Simulation

Both simulation approaches mentioned above are unsuitable for the objectives of a fast and flexible modeling of production processes. Neither an exclusive physical, nor an exclusive computer based approach can achieve a fast experimental set-up. As an alternative a hybrid simulation environment was created. It combines the advantages of digital factory with those of a Model Factory.

In the hybrid simulation environment there are physical models for the relevant production objects. They are used for the representation of the existing system by deploying a combination of software and hardware components. For every single part of simulation, the most appropriate way of simulation can be identified. The implementation of original equipment in the digital model, has the ability of testing physical effects e.g. detection rate, field intensity or antenna pointing of AutoID-elements with minimal effort [8]. Neither the purely physical nor the purely digital simulation can offer this advantage. The hybrid approach is suitable for the realization of objectives.

4.2 Procedure Model of LUPO Laboratory

To ensure a systematic approach the realization of analysis at LUPO laboratory follows the procedure model shown in figure 1.
Some of the steps which point out new ways of allowing a faster modeling and simulation with less effort are discussed in later sections of this paper .
At first, the real process is recorded with the help of multistage questionnaires. Subsequently, relevant test cases are determined. For that, the essential issues of the particular company as well as experiences made in previous analyses at the simulator are considered.
Based on these data various demonstrators are configured and adjusted to a specific requirement of the processes to be analyzed. The first step at this stage is setting up the software. The second step is the installation and connection of hardware components, e.g. RFID writing or reading units.

At the next stage the production scenario is build up in the LUPO laboratory. The machine tool demonstrators are connected with conveyer sections. After verifying the process, the analysis of alternative scenarios starts. Due to the given objectives variations are made and evaluated.

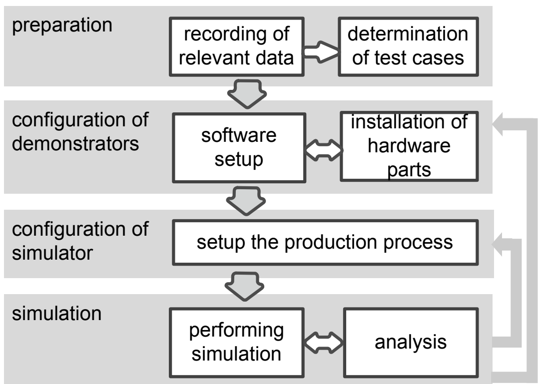

Figure 1: Procedure model of LUPO laboratory

4.3 Recording of Processes

The realization of simulation requires an adequate model of a real system. The determination of relevant characteristics is therefore an essential task. In cooperation with companies that are involved in the project several kinds of production processes are analyzed with feedback loops. This iterative procedure ensures that the knowledge gained is included and verified in order for the method to develop. Results are essential parameter of production objects to be considered in the simulation environment.

Furthermore, this method has been optimized towards an efficient communication with employees involved in production process. Hereby a fast and flexible modeling can take place without misunderstanding.

Figure 2 shows the partitioning of the questionnaire in its single elements. The first stage gives a general overview and allows a clarification of specific terms as well as a mapping of the real world components to the elements of the simulator. The information used and communication technology is analyzed regarding the used application systems for job control, quality management and machine control as well as communication channels between the single participants. The level of detail is determined by the objectives of the planned analysis.

The second stage deals with the manufacturing machines. For each machine, data should be ascertained in a separated questionnaire. It is used for the analysis of physical characteristics and information of boundary conditions that are necessary for a trouble-free operation of the machine. In addition the used tools are relevant.

The specification of work piece ist done analogously to the machine. An essential component is the description of the physical elements. Du to machinary, the conditions of the work piece changes during a production process. These different states have to be considered.

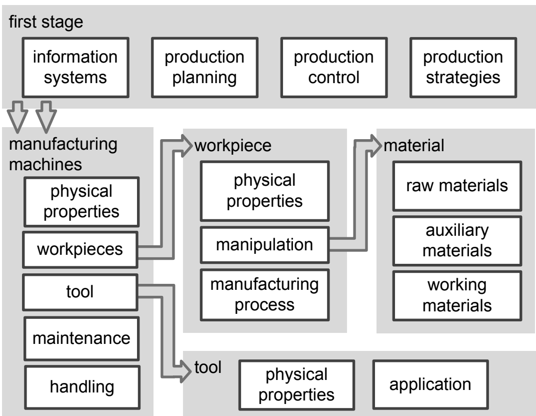

Figure 2: Structure of questionnaire for analysis of relevant parameters of production objects

In addition further components can be used in manufacturing processes. Therefore raw materials, consumables and supplies are recorded at the second stage of the questionnaire. The results are used for the configuration of work piece demonstrators.

The third stage covers the process data. This includes the description of conveyer lines between the different machine tools, storage, communication and information exchange within the process as well as the influence of production strategies and principles.

4.4 Library of Production Objects

Additionally to the recording of process data a second important and effort determining factor is the configuration of demonstrators. A library of production objects helps to reduce this effort.

In this library the data taken by the questionnaires are stored. This enables a fast simulation of a typical situation by reusing and modifying existing configurations of production objects. With an increasing number of executed simulations more objects are available with the benefit of modeling directly from library with less adoption work.

Every library object implies a suitable degree of abstraction and parameterization. This also includes dependencies and the definition of the range of its parameters. Additionally, the assignment to the user or simulation operation level is notified. This is important for the implementation of simulator software.

4.5 Level and Intensity of Simulation

Another aspect is the distinction the which way in which - hardware or computer simulation - properties are represented within the demonstrators. According to the objectives and general conditions it may be necessary to use different versions of realization. There is a scale of evaluating the situation to find the best mix of hardware and software realization for certain kinds of process and analyzed research areas. This classification enables a fast decision regarding the kind of implementation.

4.6 Construction of the Hybrid Simulator

The LUPO simulation environment consists of a composition of physical and computer based models. The main components are the work piece and the machine tool demonstrators as well as transport lines that connect the various machine tool demonstrators.

The demonstrators with their ability to communicate in different ways and their flexible transport system do provide an effortless integration of hardware components into the overall system. The software is designed for a quick integration of sensors and other devices using standard communication protocols. The hardware section provides the interfaces for an easy connection. The simulation environment is both software architecture and a hardware platform. The system supports the integration of hardware-components by design. This is an important advantage compared with pure software models which are supplemented by some hardware parts. For an investigation of receiving characteristics in a RFID-scenario, for example, it is not sufficient to connect merely a reader device, but in addition it is necessary to realize moved work pieces with a kind of conveyer. A cost intensive construction of further hardware parts is imperative for good results. Thus, the presented approach avoids these efforts.

4.7 Design and Implementation

A demonstrator consists of a box which is configured with the parameters of a certain production object. The interaction of demonstrators allows the setup and simulation of a whole production process. Relevant environmental information is delivered for input by various sensors. Some interface and communication modules allow the connection of different types of sensors and enable the interaction with other components. Thus, it is possible to configure demonstrator and complete them with further pieces of hardware. Figure 3 illustrates the setup as a matter of principle.

The illustrations 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 reporting the relevant product, process and job information. All of this information is up to date at every time during the simulation.

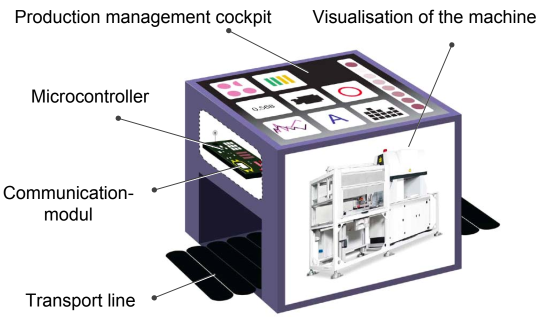

Figure 3: Concept of the machine tool demonstrator used in LUPO laboratory

The diverse machine center demonstrators are aligned by transport lines. To ensure a high level of flexibility and adaptability to the simulation environment transport, several line elements like switch plates, circular shelves as well as entry points and gates are used. Various factory layouts with sequences, parallelism or repetition can be represented. For process control of the simulated production processes, it is necessary to use corresponding software tools. Especially a MES and related Enterprise Resource Planning (ERP) software is required. Through this combination, a realistic construction of those companies that have to be simulated is possible. The LUPO simulation environment provides a MES of a project partner company, which is an experienced software manufacturer with a system used by many enterprises.

4.8 Modeling

A modeling method had to be selected for the documentation of different scenarios being simulated in the hybrid simulation environment. In accordance with criteria different methods, e.g. Value Stream Design (VSD) and Event driven Process Chain, were compared.

The most important criteria are

- suitability of the method for production processes;
- good opportunity to evaluate the production process;
- good opportunity to compare various production processes;
- high amount of clearness to simplify the communication with other persons;
- possibility for the consideration of special requirement of autonomous technologies.

The comparison revealed that Value Stream Design is the most suitable method for the aims of the LUPO simulation environment. This method fulfills the first four of the requirements mentioned above. The original Value Steam Design method does not consider the special requirements for the analysis of processes using autonomous technologies. As this is of high importance for the analysis of production processes in the LUPO simulation environment it is necessary to extend the method.

5 Extension of Value stream design for autonomous production systems

It is necessary to have a suitable method for documentation and analysis of simulation of autonomic processes at the LUPO hybrid simulator. There should be an opportunity for creating an easy overview, whether a process acts autonomously or not. A comparison of different processes towards their degree of autonomy is possible. By an additional documentation of data which is relevant for autonomous control, traceability increases. Furthermore a reproducibility of the process is given. For the process evaluation an index that measures the degree of autonomy is introduced.

Since Value Stream Design is easy to understand and practical directly at the workflow without great effort, the extension should be the same way.

5.1 Value Stream Design

Originally designed for mass production in automotive industry at Toyota, the Value Stream Design method took on significance even for small batch production in recent years. One of the main reason for this is globalization and linkage in changing market conditions. For many companies Lean Production becomes focus of attention.

By distinction of value-adding (non waste) and non-value-adding (waste) processes it is a good way to analyze the current situation of the production towards lean aspects. Sources of waste can be discovered - the basis for improvements is given. Based on the findings gained, different production scenarios can be compared and analyzed. Therefore VSD and Lean Production are a good combination for long lasting improvements [26].

For modeling, the method offers a clearly arranged symbolism that considers different properties of a supply chain such as production processes, inventory, customer, supplier and material flow. Furthermore relevant key data (e. g. lead times, waiting times, set-up times, number of persons at one process, stock) are mapped. Information flow is also of interest but the focus of this method is on material flow [27][28].

After all relevant data is recorded, the analysis starts. Value-adding and non-value-adding times are separated and its total amount is calculated. The relation of value-adding and total process time is called Lean Index. It is expressed in x:y (x to y with x= value-adding times, y=total process time). The more similar both numbers are, the less (time) waste can be found in the production. A Lean Index of 1:1 presents a perfect one piece flow with no waiting times for the products, and complete adjusted cycle times. Nowadays the Lean Index in many companies is bigger than 1:y>100 [27][28].

Figure 4 shows an example of a Value Stream Map of a production site with three processes. The supplier delivers the goods to a production supermarket. From there Process A takes them in. After finishing the procedures at Process A the goods are given into a FIFO line to Process B. Another FIFO line connects Process B and Process C. After Process C is completed all goods are put into inventory where they have to wait for a certain time. From there the products are delivered to the customer. All customer and supplier processes are like a black box. They exist but no further information is known. External processes are similar. The only figure that is known is the total process time [27][28].

Relevant data of a process which is noted in the process box might be the number of workers at the process, the capacity, set up time, process time or lot size.

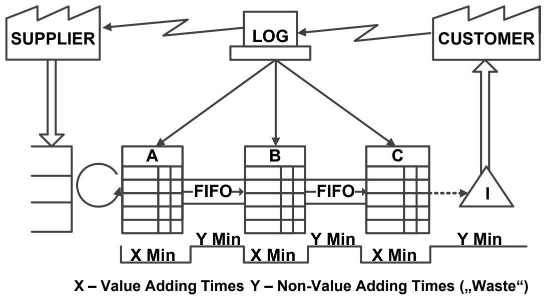

Figure 4: Example of a Value Stream Diagram

5.2 Symbolism

In order to create an easy overview as to whether a process acts autonomously or not the symbolism of processes has to be extended. The extension has to be easy so that it can be made without a great additional effort directly during the mapping of the value stream on the shop floor level. An autonomous process is marked with a black top on the right corner.

During Value Stream Mapping the author of the diagram can decide whether a process is autonomous or not and mark the process, if necessary.

5.3 Data Dictionary

For the reproducibility of the autonomous process it is necessary to document all data that is relevant for process execution. This includes all data that is exchanged between production objects that are involved in the process as well as data that the process needs to decide how to act. The relevant data can be divided into three super classes: process data, information flow data and product data. Process data is specific for the process. It includes all information that is necessary to enable the process to make decisions on its own. Information flow data specifies the data exchange of the production objects at the process (e.g. process and product). This data is necessary to rebuild the technological settings of the process. Product data specifies the product that is worked on in the process. Process data and information flow data require particular values. As there may be various products in one specific process product data are Boolean type. It is necessary to know what product data is exchanged without a concrete definition. Relevant data may be (but is not limited):

- Process Data
  - Predefined rules stored
  - Set-up time matrix
  - Amount of different products being worked on the specific process
  - Process times for different products being worked on the process
- Information Flow data
  - Data-On-Tag or Data-On-Network
  - Used technology for data exchanged
  - Frequency of information exchange
  - Amount of exchanged data per information exchange
  - Amount of exchanged data per period
  - Mission critical index – what happens in cases where the data needed is not available
- Product Data
  - Type of product
  - Relevance (express order or not)
  - Planned completion date
  - Additional information

5.4 Autonomy Index

For the evaluation of value streams with autonomous technologies the introduction of a key figure is necessary. To underline the interest it is named "Autonomy Index". It specifies the degree of autonomy used at the value stream. In coherence with the Lean Index the Autonomy Index should clarify the amount of autonomy in comparison to the whole value stream. When defining the index the basis for the comparison has to be specified. There are a number of possibilities:

- number of autonomic processes : number of all processes
- autonomous controlled process time : total cycle time
- autonomous quantity of data : total quantity of data

Due to high importance of data exchange in Autonomous Production Control the decision was made in favor of the third possibility. The Autonomy Index AI is calculated as shown in equation 1.

With an orientation to the Lean Index AI is noted as DE_{aut} : DE_{all} . The range is between 1:X (X means big number) and 1:1. The smaller the figure on the right side the higher the proportion of autonomy at the value stream. For documentation AI is written down on every Value Stream Map.

$$AI = \frac{\sum_{i=1}^{n} F_i * A_i}{\sum_{j=1}^{m} F_j * A_j} = \frac{DE_{aut}}{DE_{all}} \qquad (1)$$

AI : *Autonomy Index*

DE_{aut} : *total amount of autonomous data exchange*

DE_{aut} : *total amount of data exchange*

F : *frequency of data exchange*

A : *average amount of data volume per exchange*

$i \in I$ *with* I : *amount of autonomous data exchanges*

$j \in J$ *with* J : *amount of all data exchanges*

$I \subset J$

n : *number of autonomous data exchanges*

n : *number of all data exchanges*

5.5 Evaluation

The calculation of AI enables an evaluation of the correlation of the Lean Index and Autonomous Control in a specific value stream. The analysis will provide information on the best degree of Autonomous Control towards the overall objective of a lean production. The graphical representation results in a scatter plot since there are different ways of achieving the same value of DE_{aut}. Additionally same values of DE_{aut} can result in different grades of Lean Index. The plot may indicate the best degree of Autonomous Control for the considered value stream.

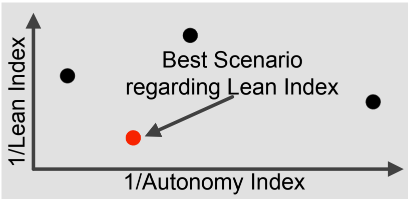

Figure 5: Example of a scatter plot

It is possible to analyze whether there are processes having major or minor impact on the decision towards an autonomous control. Based on this, a cost-benefit analysis can be indicated. The reciprocals of both data are put into a scatter plot. An exemplary evaluation of the correlation between Autonomy and Lean Index is shown in Figure 5. The scatter plot indicates that there is no correlation between Autonomous and Lean Index in the specific production analyzed in the LUPO laboratory.

6. Case Study

This section illustrates the use of the simulation environment and the modeling with extended VSD. The chosen process is the manufacturing of punching shear reinforcement. The production process consists of three stages: cutting to length of round steel, forging of flat-heads on one or on both sides and assembling of to chains with the help of flat strips. Variants have to be produced: various lengths, three sorts of material, one or two flat-heads and different numbers of pieces per assembly. In the process there was a problem at the forging machine concerning the identification of workpieces which has to be constructed, and thereby its parameters for forging (e.g. material and temperature) were not identified correctly, and the result was low quality or in some case damaged. After the process acquisition within one day, the corresponding test cases were defined. Possible solutions were an improvement of the barcode system or the use of RFID for correct identification.

Barcode case: In this scenario we use the original reader system of the forging machine insertion unit. The labels are virtual on screen of the workpiece demonstrator with various size, orientation and degree of pollution. This combination allows an effortless test of imprecisely placed workpieces and avoids an acquisition of data for a statistic based implementation for a pure software simulation.

The first test case is based on the supposition, that the labels are too heavily polluted by the previous machinery and transport operations. Performing the simulation with different degrees of polluted virtual labels could not verify this hypothesis. So the team defined another test case based on observation of previous simulation runs. It follows the idea of changing the angle between the surface carrying the label to the reader. This scenario was easier to implement in hardware than in software. A simple modification within the transport line allows a positioning of the work piece with different angles. As a result the critical angles are identified. With this knowledge the enterprise will probably invest in a modified insertion unit with an improved reader.

RFID case: For an efficient implementation the RFID technology has to be installed to the whole process. In the simulation scenario the demonstrators for all stages are supplied with RFID. One stage is equipped with a real reader device the others in a virtual way, due to costs. The operating software of demonstrators ensures that the interaction of software and hardware based parts and the integration of the real components are easy. The result is not only a reduced failture at reading but also a shorter output time. Thus, the simulation delivers arguments for future management investment decision.

Both scenarios are mapped in the extended VSD and autonomous processes are marked. Relevant data is written in the data dictionary. Lean and Autonomy Index is determined and mapped in a scatter plot. It's analysis enables a statement towards the correlation of both key figures for the concrete processes. The benefit of autonomous technologies towards the lean design of processes can be determined.

7. Conclusion and Outlook

The hybrid simulation environment provides a fast and effortless way for the simulation of production processes especially concerning the usage of new technologies and alternate production planning. The suggested methodology allows analyzing different fields of operation - ranging from proof of concept to process optimization according various criteria. The main applications are economic feasibility studies and profitability analysis. Within the specification of test cases it contains the definition of targets and objectives, thereby in a specific context profitability stands for, e.g. higher quantities, full utilization of machines, low stocks in storage. Alternative scenarios can be performed without using expensive components. Thus the simulator helps to answers the question of whether the use of a new technology is in an acceptable relation to its costs.

SME will gain the possibility to analyze their processes in a holistic way. Reliable statements towards the efficiency of concrete production scenarios with new technologies and strategies of production management are provided. The distribution of new technologies especially in SME will be promoted. The advantage of hybrid demonstrators is the flexibility to different types of machines and production processes. Due to this simulation oriented recording of processes the main characteristics which should be considered at the simulation elements are identified quickly. The creation of a library of production objects is in progress. An index helps to decide the best way of simulation - by software or by hardware - for typical parts of production processes.

The software system for the demonstrators is another work package. Maintaining the necessary flexibility for experimentation is a challenge for software architecture. The software will be extended to an automated enquiry of relevant data necessary for the modeling with the extended Value Stream Design.

Regularities are worked out with the creation and comparison of numerous scatter plots. It is examined

as to whether it is possible to define rules. It is also considered that those rules may be valid for sub-sectors only. Those sub-sectors can be split between different branches, number of processes and further aspects that have to be figured out.
The area of demonstration with the LUPO simulation environment will be extended to company-wide supply chains. This enables a grounded evaluation of the benefits of autonomous technologies in this area.

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