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Abstract

Due to an increasing market pressure and strict customer requirements a high adaptability of production processes becomes more and more important for producing companies. To be successful on the market it is necessary to produce in an efficient way and minimize non-value-adding production. Autonomous, self controlled production systems are one possibility to handle these demands. The purpose of this article is the extension of the Value Stream Design method towards the requirements resulting from the simulation of autonomous production processes. For this purpose additional symbolism, data dictionaries and key figures are introduced.

Keywords:

Autonomous Production; Value Stream Design; Self Control

1 INTRODUCTION

In recent years the market more and more shifted from a sellers' towards a customers' market. Reasons for this are among others the globalization and the associated possibility for all customers (end customers as well as companies) to order the same products at many companies all over the world. For that reason customers increase their bargaining power. Producing companies are forced to fulfil the customer requirements on a high level. They have to be able to adjust the production in a fast and adequate manner. Decentralisation of production control is a chance for production companies to deal with these increasing requirements.

By the decentralisation of decision making the power of decision making is shifted from a central unit towards the single production object such as machine tool, work piece or tool. Hereby a direct consideration of current production states is possible. The autonomous production control enables companies to have a fast and simple adjustment towards the company's objectives like short throughput times, lower stocks or a high adherence to delivery schedules. Adjustments especially in detailed production planning – e.g. adoption of order sequence and lot size – can be done quickly and target-oriented.

For the analysis and continuous improvement of supply chains it is necessary to create a holistic view of all current processes as well as the information flow. One suitable method for this is Value Stream Design, which originally was designed by Rother and Shook for analysing the value stream of Toyota's mass production. Due to the differentiation of value-adding and non-value-adding times it is a good approach to find potentials for a lean production without 'waste' – a term used in the lean philosophy for all parts of the production process that does not add a customer value to the work piece.

This article pictures the special requirements of modelling and analyzing autonomous production processes. Demonstrated with the concrete example of the LUPO simulation environment the requirements for the analyses of autonomous production processes are shown. After a brief presentation of the LUPO project, the concepts of Value Stream Design and Autonomous Production are clarified. While in Value Stream Design information flow plays a minor role in contrast to material flow it is of major significance in terms of autonomous production control. Value Stream Design is adjusted to the specific requirement of autonomous control due to the extension that is shown in chapter 2. The case study in chapter 3 clarifies the usage of Extended Value Stream Design in an exemplary production.

1.1 LUPO Project

The LUPO (LUPO is the abbreviation in German for 'Leistungsfähigkeitsbeurteilung unabhängiger Produktionsobjekte' (Productivity evaluation of autonomous production objects)) project's aim is to detect which autonomous technologies in which combination help to increase the adaptability and, consequentially, 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 autonomous technology [1].

To achieve those objectives a hybrid simulation environment is created. It combines the advantages of the digital factory with those of a model factory. The disadvantages are minimized or eliminated wherever possible. It 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 of the work-piece 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 [1].

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 [1]. Additionally, certain physical effects like field strength, alignment of aerials or detection rate can be analyzed easily [1].

A modeling method had to be selected for the documentation of the 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. This paper constitutes this extension.

1.2 Value Stream Design

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

The main goal of this approach is to identify non-value-adding processes (waste) in production. 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 with regards to 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 [2].

VSD consists of several steps: the creation of the Value Stream Mapping (VSM) that illustrates the current production process, the analysis of the VSM and the Value Stream Planning (VSP) that illustrates a new and leaner production process, which is based on the potentials developed in the previous step. 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 [3][4].

The procedure for VSM is easy but effective. In multiple passes a team of several people from different departments walks through the shop floor. Beginning with the last production process, they map all relevant data directly in a diagram. To gather a good quality of the data it is absolutely necessary to ask those workers who are directly in contact with their processes. This participation enables the team to gain information which is not visible for them. Additionally it is advisable that one of the team members is external

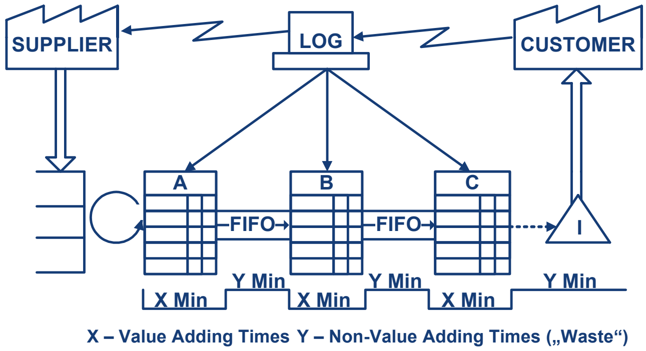

Figure 1: Example of a Value Stream Design Map

and not blinded by routine. This will also help to make these facts more obvious for those who are in daily contact with this specific production line [3][4].

After all relevant data are recorded, the analysis starts. Value-adding and non-value-adding times are separated and its total amount is calculated. The quotient of value-adding and total process time is called 'lean index'. It is expressed in x : y (x= value-adding times, y=total process time). The more both numbers are equal, 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 at 1 : y>100 [3][4].

One of the most important figures in Value Stream Design is the customer tact. It specifies in which period the products have to be produced to fulfill the customer demands. As lean manufacturing is a customer driven approach, all processes have to be aligned to this tact [5]. In most productions the customer has one or more customer with own tact times himself. And this customer has some of his own as well. But all these downstream information is known by the other companies. This may cause information delay and waste due to security stocks [3][4].

All processes of customers and suppliers 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 [3][4].

Figure 1 shows an example of a Value Stream Map of a production site with three processes. The supplier delivers the goods to a supermarket. From there Process A takes them. After finishing the procedures at Process A the goods are given into a FIFO line to Process B. Process B and Process C are connected by a FIFO line as well. After finishing Process C all goods are put into inventory where they have to wait for a certain time. From there the products are delivered to the customer. There is an electronic data exchange from customer to the central IT system of the analyzed company and from the company to the supplier. The data exchange from IT to the certain processes is done manually.

1.3 Autonomous Control in Production Processes

"Autonomous Control describes processes of **decentralized decision-making** in heterarchical structures. It presumes interacting elements in non-deterministic systems, which possess the capability and possibility to **render decisions independently**. The objective of Autonomous Control is the achievement of increased robustness and positive emergence of the total system due to distributed and flexible coping with dynamics and complexity" [6]. Requirements for Autonomous Control are differentiated in information processing, decision-making and decision-execution [7]:

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 [7]. Examples for such technologies are Radio Frequency Identification (RFID) or barcode [8]. 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 object to performance alternative processes is necessary [7].

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 decentralized 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 a given algorithm. Based on this, regulations are proceeded [7].

Autonomous Technologies are a combination of hardware, operating system, networks and software. 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 to the relevant sites. Autonomous Technologies enable systems to an autonomous and decentralized control of themselves. They are understood as a generic term for the realization of self-acting control of single elements of this system [7]. Figure 2 shows the division of Autonomous Technologies into three levels of hierarchy [9].

Basic Technique: Description of the single AutoID-element (e.g. RFID tag or barcode label) that is tagged on the single production object for saving those data that are relevant for the autonomous control.

Bundle of Technologies: A System consisting of multiple basic techniques as well as reading components. It is used for the recording of information that is stored on the production objects by basic techniques. There is only a data transfer without a processing or analysis of information [10].

Autonomous System: A system is an amount of elements which are related to each other. Each element is connected to another directly or via a third [11]. An autonomous system combines bundles of technologies, production control concepts and organizational strategies. Hereby the system, respectively selected parts, is enabled to identify its current state. Due to matching predefined conditions, e.g. the achievement of characteristic values of key figures, necessary process steps are identified.

The usage of Autonomous Technologies has a high potential. In particular new possibilities in the automation of the value stream are created. While the common production control uses centralized decision processes, Autonomous Technologies allow storing relevant data on the product itself. The current separation of the physical product and its belonging information flow is removed. Software systems, like Manufacturing Execution Systems (MES), help to realize the decentralized analysis, decision-making and basing control [12].

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 have to be recalled and updated submitted. In contrast, additionally to the numeric code all object oriented data are tagged directly to the object within the decentralized data storage. Thus, data volume and reaction time are reduced [13].

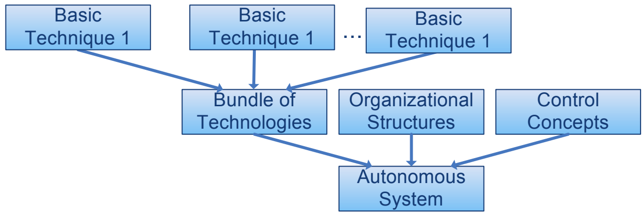

Figure 2: Levels of Hierarchy of Autonomous Technologies

One of the most common Autonomous Technologies is RFID. The relevance of Autonomous Technologies will increase significantly in the coming years. Until 2016 an average annual growth of up to 25% is expected on the RFID-market. Nowadays RFID is used in various fields of application in economy, military and leisure. In economy it is mainly used in transportation (31%), production control (18%) and product information (16%) [14].

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 [15][16]. In general, attempts to first adopt RFID in sub processes, as a means to verify the benefits and profitability, and then to extend the RFID support to the entire process has been made.

There are noticeable differences in the distribution of RFID in small and medium sized enterprises (SME) in comparison to major enterprises. While almost 50% of the major enterprises used RFID in 2008, it was only 22% in SME. 22% of SME marked RFID as unsuitable for their company (major companies: 8%) [14]. Reasons for limited distribution of RFID in SME are above all high initial costs for the technology as well as uncertainty regarding the fulfilment of the objectives [14]. 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 [17].

2 EXTENSION OF VALUE STREAM DESIGN FOR AUTONOMOUS PRODUCTION SYSTEMS

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

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

2.1 Symbolism

For creating an easy overview whether a process acts autonomous or not the symbolism of processes has to be extended. The extension has to be that easy that it can be made without a great additional effort directly during the mapping of the value stream on shop floor level.

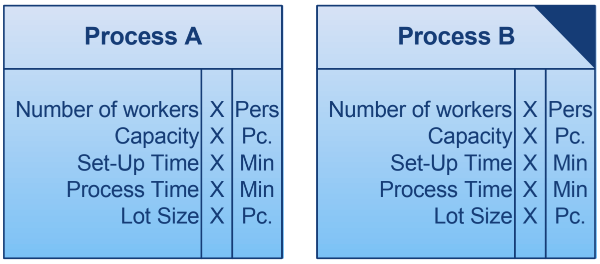

Figure 3: Extended Value Stream Design Process

(a) Non-Autonomous Process (b) Autonomous Process

Figure 3 shows the documentation of two processes with some exemplary characteristics. Further information might be the amount of variants produced at this process, the key figure EPEI (Every Part Every Interval) that specifies the duration a process needs to produce all available variants or the technical availability. While Process A is non-autonomous Process B is marked as autonomous.

The process is able to make objective decisions on its own. The marked top right corner indicated the autonomous character of the process. During Value Stream Mapping the author of the diagram can decide whether a process is autonomous or not and mark the process, if necessary.

2.2 Data Dictionary

For the reproducibility of the autonomous process it is necessary to document all data that are relevant for process execution. This includes all data that are exchanged between those production objects that are involved in the process as well as those data the process needs to decide how to act. The relevant data can be divided into the three super classes: process data, information flow data and product data. Process data are specific for the process. They include all information that is necessary to enable the process to make decisions on its own. Information flow data specify the data exchange of the production objects at the process (e.g. process and product). They are necessary to rebuild the technological settings of the process. Product data specify 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 of type Boolean. It is necessary to know what product data are exchanged without a concrete definition. Relevant data may be (but are 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 (e.g. barcode or RFID)
  - Frequency of information exchange
  - Amount of exchanged data per information exchange
  - Amount of exchanged data per period (e.g. day, week or month)
  - 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

2.3 Autonomous 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 "Autonomous Index" (AI). It specifies the degree of used autonomy at the value stream. In coherence with the Lean Index that conciliates the value-adding-time to the total cycle time, the Autonomous 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 autonomous processes : number of all processes
- Autonomous controlled process time : total cycle time
- Autonomous quantity of data : total quantity of data

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

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

with:

AI: Autonomous Index

DE_{aut}: total amount of autonomous data exchange

DE_{all}: total amount of data exchange

F: frequency of data exchange

A: average amount of datavolume per exchange

$i \in I$: autonomous data exchanges

$j \in J$: all data exchanges

$I \subset J$

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

2.4 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 to achieve 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. Potential correlations of both key figures can be detected. It is possible to analyze whether there are processes having major or minor impact on the decision towards an autonomous control. Based on this information a cost-benefit analysis can be indicated.

3 CASE STUDY

This section provides an example for the usage of extended Value Stream Mapping in connection with simulation of production processes in LUPO the laboratory.

The analysed production consists of five processes (process A to E). The production sequence is predefined and identical for all products produced. The process can be classified into two sections that are linked by an interim storage. This storage is the point of individualization. The first section consists of process A and B. Both produce non-individual products. Products handled at process B are put in an interim storage. There are two variants produced in this section. Processes C to E produce customer individual products. Intermediate products are taken from the storage and then handled in process C. There are three variation possibilities in process C and D, two in process E. All of those possibilities are combinable, so that there are 2x3x3x2=36 variations of the end product.

For the change from one to another variation on one process setups are necessary. As set up times vary from initial state to target state, there are setup matrixes for all five processes. Process times differentiate from process to process as well as from variant to variant. For satisfaction of the customer requirements it is of major importance that the right product is manufactured at the right time. Recently the delivery performance deteriorated and stock rose. It is for this reason that all processes should be reconsidered. Additionally to the mentioned problems it should be analyzed how to deal with express orders, that ensure a highly shortened delivery time to customers.

At the current state all five processes are central controlled. While there is a push control at the first section there is a pull control at the second section. The produced amount of both basic variants in the first section is planned due to a sales forecast that is based on past experience. The production program for the next week of the second section is planned due to concrete customer orders. Difficulties arose due to missing intermediate products. All five processes with their relevant characteristics are recreated and simulated at LUPO laboratory. After the validation of simulation results with the existing processes variations towards the type of control are made. In addition to a complete centralized and decentralized control mixed control concepts are analyzed. Therefore the first section is set decentralized controlled while the second is central controlled and the other way around. Substance differences are perceived at lead times and stock building.

For each set-up a value stream map is created and a value stream analysis performed. The Lean Index is calculated by dividing value adding process time by total process time. For the evaluation of the processes by means of the Autonomous Index it is necessary to determine the average amount of datavolume per exchange and the frequency of data exchange at all process – for both central and decentral controlled ones. On the basis of these values AI is calculated. Assuming that as well the average amount of datavolume per exchange as the frequency of data exchange are identical in all scenarios the relevant data for the scatter plot can be determined with Table 1 and Table 2:

Process	Average amount of data volume per exchange	Frequency of data exchange
A	1	3
B	2	3
C	3	3
D	3	3
E	2	3

Table 1: Characteristics of processes

Scenario	**AI**	**LI**
1 (complete decentral controlled)	1:1	1:50
2 (complete central controlled)	1:∞	1:45
3 (first section decentral, second section central controlled)	1:3,67	1:70
4 (first section central, second section decentral controlled)	1:1,5	1:10

Table 2: Characteristics of scenarios

The reciprocals of both data are put into a scatter plot. The evaluation of the correlation between Autonomous and Lean Index is shown in the scatter plot (Figure 4). The scatter plot indicates that there is no correlation between Autonomous and Lean Index in the specific production analyzed in the LUPO laboratory.

It is obvious that the best Lean Index is realized with AI = 1:10. This situation occurs if the first section is controlled central and the section decentralized controlled. The worst Lean Index is achieved by a decentral controlled first section and a central controlled second section (AI= 1:3,67). The change of a complete central production (AI=1:∞) to a complete decentralized production (AI=1:1) only causes marginal differences in consideration of the lean-index.

For all decentral controlled processes a supplementary analysis is realized. Its results are recorded at the data dictionary. This enables a later reproduction of the process and therefore the usage of identified advantages in the real production. Additionally the extended value stream maps enable a well-founded discussion with company internal and external persons.

The best mix of central and decentral controlled production has been determined. The problems of the original process mentioned aboved were reduced to a minimum. Due to a well arranged and completely documentation regarding lean production aspects, a successful implementation of simulation results in real production processes is provided.

4 CONCLUSION

This paper presents an extension of Value Stream Design for its usage for autonomous and decentralized production processes. Because of this extension it is possible to transfer the advantages this method provides to autonomous processes without a negligence of the special characteristics decentralized processes entail. The documentation and evaluation of data with the help of scatter plots enable a clear and meaningful representation of the correlation between Lean and Autonomous Index.

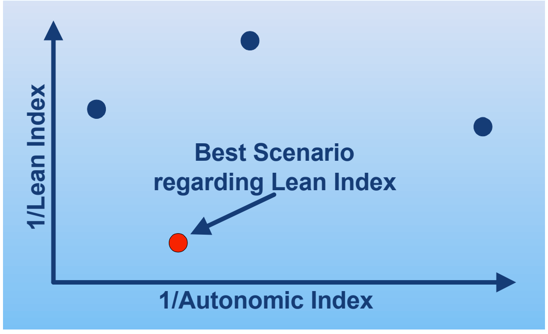

Figure 4: Scatter plot for analyzed production processes

Advanced tasks result after the creation of the described method for the documentation and analysis of Autonomous Production Processes their suitability for a lean value stream. It is necessary to ascertain the occurring data volumes with the least necessary effort in a high quality. For this purpose the software used in the hybrid simulation environment has to be extended. The aim is to achieve the possibility for a completely automated enquiry of all data volumes during the simulation process. In a second step these data are assigned to extended Value Stream Design.

Besides this, a template for the data dictionary is necessary. On this account a number of different autonomous processes have to be analyzed firstly. All relevant information of those processes are extracted and documented separately. A comparison allows the recognition and filtering of recurring data.

Moreover, with the creation and comparison of numerous scatter plots regularities are worked out. It is examined whether it is possible to define rules regarding specific industries or manufacturing techniques.

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