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Arbeitsbericht WI - 2011 - 05

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Zitierhinweis: Gronau, N.; Fohrholz, C.: The manufacturing adaptability scorecard - a tool to analyze the benefit of autonomous production processes. Proceedings of the 4th International Conference on Changeable, Agile, Reconfigurable and Virtual production (CARV 2011). Montreal, Canada. October 2011. Springer Verlag, München, 2012.

The Manufacturing Adaptability Scorecard - a tool to analyze the benefit of autonomous production processes

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Abstract

The Balanced Scorecard, developed by Kaplan and Norton [1], is now a reliable and often used instrument of strategic management. While a huge number of applications can be found in business administration and financial management, not so many BSC's could be found in manufacturing realms. While the need for adaptability is clear for most manufacturing companies it remains difficult to hold a clear and steady course to an increased status of manufacturing agility. In this paper we present a BSC approach suitable to foster manufacturing agility.

Keywords:

Adaptability, RFID, Value

1 INTRODUCTION

Businesses are in a constant process of change due to the influence of external factors or due to self-initiated processes of change. Changing of quantities or the introduction of different lot sizes in production influence the production processes. To these global interferences comes local influences. The internal business supply chain is vulnerable to disruptions, for example through the breakdown of a machine. In that case, efficiency as well as the mutability of the common production system is essential in order to successfully participate in the market affairs. Therefore, organizations have to react as fast and as flexible as possible in order to adapt their systems, their processes or even their internal structures to changing basic conditions effectively. Adaptability is the main issue regarding these influences and it illustrates an approach to the business reaction. A system's ability to perceive and manage modified external requirements efficiently as well as effectively, defines in this case adaptability.

The implementation of autonomic technologies like RFID or sensor technology is widely discussed in the industry. The question for most organizations is not only whether to apply the technology but rather to learn something about its advantageousness. The main barrier to the implementation, especially for small- and middle-sized businesses, is the question of value. Various problems or risks can be accompanied by an investment. To these belong, besides the necessary financial investment also, as the circumstances require the adjustment of the internal workflow or manufacturing processes. Such a project locks up resources throughout a long period of time and it creates significant repercussions along the business processes within the company. Project costs can be determined through relatively easy methods such as cost accounting. Much more difficult, but a lot more significant at this point is the determination of the value that can be opposed to the costs. The following questions are relevant to the context: What autonomic technologies and in which combination is it possible to raise the adaptability, in what branches and processes, of the producing businesses and therefore the companies' competiveness?

This paper puts a possible answer to this question – The Manufacturing Adaptability Scorecard (MAS) – to discussion to emphasize the pros of the autonomic technologies' implementation.

2 ABOUT THE BALANCED SCORECARD

The Balanced Scorecard (BSC) was originated at the beginning of the 90´s by P.S. Kaplan and D.P. Norton as a performance measurement framework. The BSC added strategic non-financial performance measures to traditional financial metrics to make it possible for managers to focus on a handful of measures that are most critical [1]. Quantitative indicators have been used to measure the profitability of an organisation ever since. But the usage of qualitative factors has become more important for the control of business processes. Today, the BSC is one of the most used instruments for the strategic management and control [2]. The scorecard measures organizational performance across four balanced perspectives: financial, customer, internal business processes and learning and growth [1]. The perspectives stand in a cause-effect-relationship to each other. For each of these perspectives four things are monitored [3]:

- Objectives: the major objective that has to be achieved,
- Measures: the parameters that will be used to measure the progress toward reaching the objective,
- Targets: the specific target values for the measures,
- Initiatives: projects or programs to be initiated in order to meet.

The measurements should be focused on a single strategy and be linked, consistent and mutually reinforcing. Meanwhile, Balanced Scorecards are used for a lot of use cases. These include for example typical BSC for special industries, e.g. health care, or for a certain problem or project. The subject of measuring the performance in the manufacturing area has been object of research in the last years. Gomes et al. reviewed 388 articles, published in 144 Journals, between 1988-2000 and some relevant conference proceedings. They concluded that on the basis of the review, the BSC is the most often cited performance measurement system [4].

This could be a reference for the usage in practice. A study from 1998 estimated that nearly 60 percentages of the fortune 500 companies have implemented a BSC or their working on it [2].

For the implementation of a Manufacturing Adaptability Scorecard (MAS) it is interesting to have a look at recent concepts and practices in manufacturing performance. In particular, Key Performance Indicators (KPI´s) can be used to determine possible parameters for the MAS. KPI´s represent a set of measures focusing on those aspects of organizational performance that are the most critical for the current and future success of the organization [5]. Table 1 shows a selection of the many possibilities. It is obvious that the measures and indicators used in a BSC made for a specific industry, situation, questioning or a particular level of operation in the organization. So, this list is non-exhaustive and is only provided to illustrate some typical KPI´s in manufacturing.

Perspective	KPI
Financial	Economic Value Added (EVA), Earnings before Interest and Tax (EBIT), Product cost per unit, Quality cost, Earnings per share
Customer	Customer Satisfaction Index, Market Share, Part of new customers,
Internal Business processes	Time from Error Localization to Correction, Complaints Percentage, Employees productivity, Throughput Time, Production cycle time, Capacity utilization, Process Losses
Learn and growth	Educational Effectiveness Index, Employee Satisfaction, Percentage of Man-Hours in Training, Motivation index

Table 1: Selection of KPI´s [6, 7].

Also relevant in the context of that paper and the MAS is the concept of adaptability. As described before, organizations have to contend with massive changes and the influence of internal and external factors. Adaptability is an approach to respond to these requirements.

3 THE CONCEPT OF ADAPTABILITY

3.1 Definition

Adaptation is a key feature of natural and artificial systems [8]. These fields define the problem space which produces adaptive processes. Holland defines adaptive processes as optimization processes [9]. As structures being modified are complex and uncertain, it is difficult to subject adaptive systems to unified studies. Historically, adaptation provides the foundation of the research domain adaptability. Flexibility, agility and adaptability are often used interchangeably. The definitions of flexibility vary by application. A classic manufacturing industry definition describes flexibility as a measure for the range of reachable states and the time and cost required for moving from one state to another and was introduced by Slack in 1983 [10], another is the ability to change or react with little penalty in time, effort, cost or performance [11]. The most essential qualities of flexibility comprise the capability of a system to adapt to changes with (nearly) no penalty in time, cost or performance. Furthermore flexibility can be characterized as an initial investment in specific pre-set upper and lower boundaries aimed at a long-term planning horizon [12]. Within the context of systems thinking a flexible system should have the ability to effectively adapt or respond to environmental change to take advantage of opportunity and to minimize threats [13]. Agility has been discussed in the literature under various aspects. The approach on agility is not explicitly based on systems theory [9]. However, most authors agree that is the ability to rapidly respond to an external and unexpected event. The argument promoting agility is that it enables better survival in turbulent market conditions [14, 15]. Business agility is rapidly becoming a management focus to be more competitive in a global economy. Speaking of adaptability its characteristics need to be defined to be able to identify and design for adaptable processes and derive demands on the process model [16]. A model according to these criteria will be called adaptable. The research is influenced by related research domains as factory planning (building modular factory structure), bio-cybernetics (redundant structures to ensure performance) and information systems to name a few.

3.2 Criteria for adaptability

Seven main adaptability criteria were identified, that are: self-organisation, modularity, interoperability, scalability, redundancy, knowledge and self- similarity. The first set of criteria originates from factory planning and comprises scalability, modularity, independence, and interoperability [8].

Scalability

Scalabiliy represents a quantitative quality. This indicator demands an efficient upward and downward adjustment at changed quantities of information to be processed [17]. That will be possible through a change of production capacity by rearranging the manufacturing system or e.g. by changing the capacity. One way to realize that is by using parallel production lines [18]. An additional type of a machine increases the production capacity. But it´s not guaranteed that the whole capacity will be used and on the other side there are still the fixed costs [19].

Modularity

Modularity generally means the structuring of a system into small, partly autonomous subsystems [20]. It also can be used for the architecture of products, maschines or production processes. Each component, for example a group of machines, would have their own responsibilities. Every machines or a part of a machine can be added or removed to extend or change the system capabilities [17]. Product modularity offers value by providing a broader range of products [18].

Availability

Availability is characterized by a spatial and temporally unlimited access to applications and any resources which are needed [21]. Access to data and functionality has to be granted as well as proper operating of components in the network at any time and anywhere.

Interoperability

Interoperability refers to the ability of resources to place a high measure of compatibility and connectivity. It is commonly realized by deploying interface standards in information system architectures [22]. Interoperability is needed for all components in a manufacturing process.

Self-Organisation

Self-organisation marks the ability of a system to determine the systems structure by adjusting and steering mechanisms related to processes within the system in order to ensure the long-term existence of the system [23]. Thereby the resources and subsystems produce their own order by taking up information about their environment and their reciprocal effect with the environment.

Self-Similarity

Self-similarity is a characteristic to be achieved by applying the same design principles to another size scale. Form and function are similar but not its organization. Self- similarity is a phenomenon owned by many natural objects (clouds, plants, mountains etc.). The same essential structures appear in different size scales [8].

Knowledge

Knowledge is a compound of valuest, contextual information, professional insight and classified experience that individuals employ to solve problems. Knowledge is always bounded to an individual and is only used there [24]. The knowledge of organizations is not only linked in documents. It also can be found in organizational rules, processes, practices or standards [25].

As noted, there are several criteria for adaptability. But the term is still used variously and in different ways. These criteria are just one approach to define the concept of adaptability. The term is used in computer science and also in the context of production and plant implementation. So, the understanding about that differs. For the purpose of the MAS the seven criteria described are the basis for the next steps.

4 PROCEDURE MODEL FOR THE IMPLEMENTATION

4.1 Implementation Process of a Balanced Scorecard

A procedure Model contains information's about the time schedule and the logical order of tasks which are needed to achieve a goal. In addition, it contains rules and related methods. Kaplan and Norton provide an eight step model for the implementation of a Balanced Scorecard [26]. They also pointed out, that for each organization and questioning the model may be adapted. Figure 1 shows a typical project. The first step is the preparation for the implementation. Its aim is to define the business unit for which the BSC is needed. In the next step Kaplan and Norton suggests single-interviews with senior managers to describe the companies vision and the long-term strategy. The results of the interview should be discussed in an executive workshop. As a result the mission and strategy is fixed. In addition, the key success factors need to be discussed. The group has to be propose measures for each perspective. These results are summarized and discussed in interviews. In a second workshop, involving a larger number of participants, the tentative scorecard is presented. The group comments on the presented scorecard and formulate objectives for the proposed measures. During a final workshop, the senior managers have to come to a final consensus about the vision and the measurements developed. Finally, a team has to develop a plan for the implementation including technical realization, integration into operational processes and internal communication.

A wide range of authors pointed out that the implementation of an BSC in the structure of a company is not that easy as it described by Kaplan and Norton. Lack of communication is just one example of the obstacles that compromises the project [27]. The implementation of the BSC can help to lead a company effectively. Employees need understandable and trustworthy processes and messages to participate the project. The BSC must also fit in into the corporate culture. Another point is the need for the organizations to develop a comprehensive strategic approach in all its levels and activities. Typical barriers for the strategic implementation are for example [28]: that nobody understands the strategy or most people have objectives that are not directly linked to that strategy. The problems and risks listed here are just a sampling of its complete range. Despite the criticism, a procedure model for the implementation of the MAS is needed. The "typical" process as described can be used as a basis for the implementation of a suitable one. This must be complemented by a methodical procedure for the consideration of adaptability and manufacturing aspects. The first step consists in a discussion about the requirements to be met by the model.

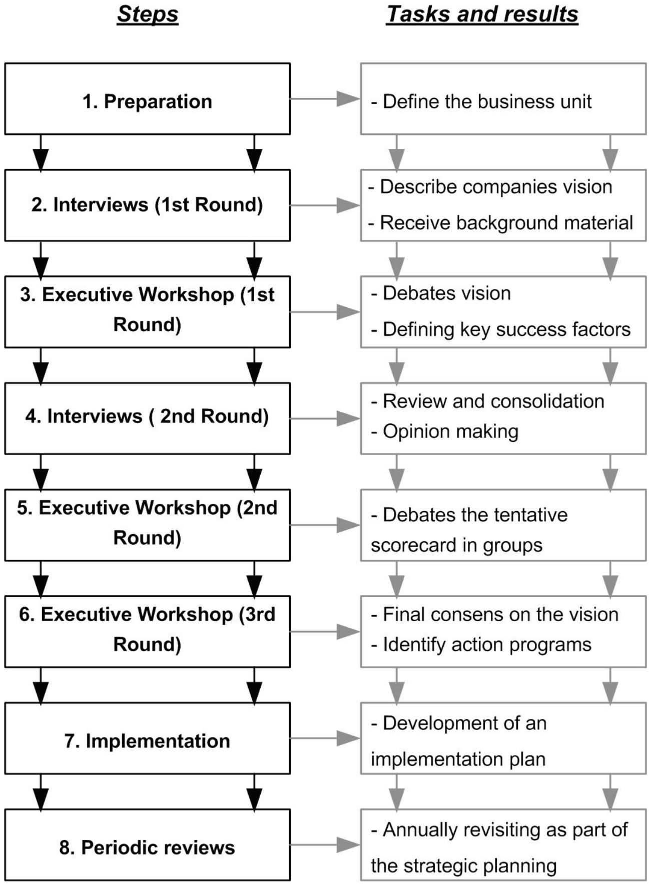

Figure 1: Implementation process of the BSC [26].

4.2 The four perspectives of the manufacturing Adaptability scorecard

Adaptability as a concept influences products, business and manufacturing processes and the supporting infrastructure. Due to the focus on manufacturing agility products are not directly considered. Environment turbulences force the business and also the manufacturing processes to adapt and to change. Therefore a *process perspective* for the MAS is necessary. The next perspective describes another source of influence of turbulences, changes and adaptation needs, the *customer* and his behavior, specially his role as an initiator of changes. One of the most important control parameters of *manufacturing is productivity*. Therefore this will be the third perspective. The main task of this perspective is to monitor which influence the changes have on productivity key figures. This approach shall assure that an improved agility won't decrease the company's productivity. The last proposed perspective covers a very important key element for adaptability - the worker. This perspective is named *learning and personal growth*.

4.3 Requirements

The determination of the advantage of an investment cannot be taken through a single indicator or the evaluation of costs. The effects of the use of autonomous technologies are multilayered and complex. The model must be capable to take into account different dimensions and indicators. Also, a procedure employed to evaluate and compare various alternatives on the basis utility values is needed.

Secondly, the observation of costs and the benefits are necessary. The implementation of an autonomous technology, for example

RFID, is associated with a lot of different costs. The consequential costs arise at different times during the whole life- or production cycle of a product. Prime examples for this are acquisition costs and costs for the launch of the technology into the business processes. Additional, costs incurred through the usage of the technology. All these cost components need to be considered in the model and will be compared with the value. An essential requirement is the determination of the effects which an autonomous technology on the business processes has. The question is "How autonomic technologies and in which combination raise value for the organization". The results of various scenarios can be compared with the criteria for adaptability.

The concept of the Balanced Scorecard and of Adaptability has been described in the previous sections of that paper. On that basis, the next step is to develop a procedure model for the design of a Balanced Scorecard which meets these demands.

4.4 The MAS Procedure model

Preparation

Based on the model of Kaplan and Norton, as described before, the first step in the MAS procedure model is the preparation. The main part of that task is the formulation of requirements to the model. As a result of that work the vision and strategy will be formulated. As mentioned before, increasing the adaptability of the production processes is one possibility to measure the impact which autonomous technologies have. For the MAS, the "Increasing of adaptability in business processes" is therefore the strategy which will be pursued. This step includes the translation of the strategy (vision) into the four perspectives of the MAS.

Finding indicators

The second step occupies with the collection of indicators for each of the four perspectives. For this, the success factors approach is used. The idea behind that concept is that there are a few factors that decisive for the success of a business. The concept is often used in the field of business strategy research [29]. For the determination of possible indicators different methods can be employed. Systematic literature reviews as well as structured interviews with experts or standardized questionnaire can be used [30]. The results are a collection of quantitative and qualitative factors. To ensure that the qualitative factors can be transformed into an indicator for the scorecard, they have to be operationalized. A solution to this problem is the usage of the times savings, time salary approach. The approach assumes that a worker or a machine for instance, loaded salary is the measure of that workers value to the organization [31]. In fact, the value for the organization is determined about the costs of workers and also machines which can be influenced by using a new technology [31]. Also, the quantitative indicators can be determined in that way. In the specific case of the MAS this approach can be used for the evaluation of autonomous technologies in the context of adaptability. That is the reason for the absence of a financial perspective in the MAS. The information´s about the cost savings (or the value which can be gained) can be determined in that way and can be compared to the whole life cycle costs. This view is a separate analysis and does not appear in the MAS.

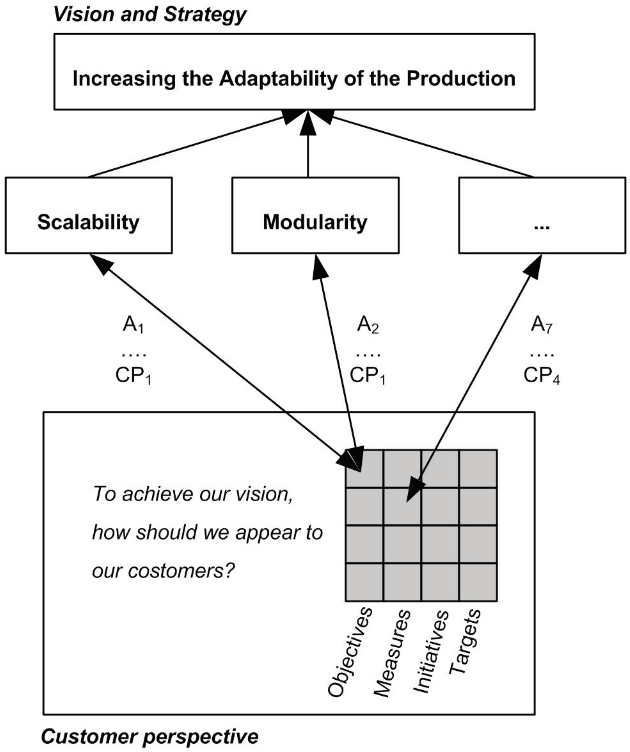

Figure 2: Example for the connection between perspective indicators and adaptability

Review and consolidation

The next step includes the collection and allocation of the Indicators to the four perspectives. But it must be made clear that at this point the scorecard consist of numerous of possible indicators. For the implementation of a final MAS, all these indicators has to be verified as part of a validation. For further analyses, the indicators can be named in that way:

- Process perspective *(PP1…PPN)*
- Customer perspective *(CP1…CPN)*
- Manufacturing and productivity perspective *(MP1…MPN)*
- Learning and growth perspective *(LP1....LPN)*

Extension with adaptability

In the fourth step then, the scorecard will be extended by the adaptability criteria. Figure 2 shows an example how the connection between the indicators and the adaptability criteria will be constructed. The assumption of the model is: that there are a small number of indicators in each perspective which has an impact on the adaptability of the business processes. Through the implementation of an autonomous technology the change of the indicators can be measured. That results in a modification of the adaptability. For this purpose, a dependency model between indicators and adaptability criteria has to be adopted. In this first stage, the connection is based on assumptions. At this point, interviews with expert and a literature review is used. Should the examination of the assumption lead to a result that there is no direct connection between both factors, the indicator will be deleted from the scorecard. But that is part of the validation and will be described later in that paper. The prerequisite for this is that the criteria for adaptability have to be operationalized.

Factors	A_1	…	A_n	Correlation
Time from Error Localization to Correction (MP_1)	X	X		.87
Complaints Percentage (MP_2)		X		.46
Employees productivity (MP_3)	X		X	.65
Production cycle time (MP_4)	X	X		.93
…				
(MP_N)			X	.24

Table 2: Exemplary functional matrix for the manufacturing and productivity perspective.

For the further analyses the criteria for adaptability will be abbreviated in the form $A_1 … A_N$. As shown in table 2, the results can be summarized in a functional matrix.

Draft version

On the basis of the acquired knowledge a draft version of the MAS can be developed. This first version of the MAS contains a pool of indicators with the corresponding connection with the adaptability criteria. In workshops, involving different experts and also typical users of autonomous technologies, the results will be discussed. The participant´s comment on the indicators and the assumptions about the connectivity with the adaptability. It is also necessary in these workshops to formulate objectives for the measures and a proposal for the rates of improvement. Also, the results have to be compared with the goal and strategy setting (see Step 1 “preparation”).

Validation

The indicators in the single perspectives can rise or fall through the impact of an implementation of a autonomous technology. By studying the behavior of adaptability criteria during that change the link between both can be determined with statistical methods and a par wise comparison (see also table 1). In the context of a project, called ”Productivity Evaluation of Autonomous Production Objects”, applied by the chair of Business Information Systems and Electronic Government at University of Potsdam, a hybrid simulation environment can be used for the validation. In the following section the aim of the project is described more detailed.

5 VALIDATION

5.1 About the Project LUPO

LUPO (LUPO is the abbreviation in German for ’Leistungs-faehigkeitsbeurteilung unabhaengiger Produktionsobjekte’ (Productivity evaluation of autonomous production. The project develops a hybrid simulation environment with the collaboration of IT- and producing-companies. With reference to concrete production processes feasible variants of organization and the usage of new technologies for production plants can be implemented in the simulator. 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 adaptive. The company is able to measure up to the continuous changes in the market. The LUPO 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 autonomic technology. 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 be detected. The project will clarify what information is transmitted in an information system and what new management and control concepts productive enterprises using autonomous and decentralized technologies need.

5.2 Usage of the Hybrid Simulation Environment

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. 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.

The LUPO simulation environment can be used for the validation of the MAS. With that environment it is possible to simulate different scenarios in production and to monitor the changes on the indicators in the scorecard. With these results it will be possible to create statements about the impact of autonomous technologies on the adaptability of production processes. With that findings the advantages which a autonomous technology has, can be figured out more effective and efficiently.

6 CONCLUSION

The aim of that paper was to suggest a model for the implementation of a Manufacturing Balanced Scorecard. As pointed out, in the context of adaptability, there are seven criteria which have to be considered in the model. The concept of the balanced scorecard from Kaplan and Norton, especially the implementation process, was described. On that basis the implementation model was created. One of the next main steps is a detailed analysis of the adaptability criteria and how they can be operationalized. Work in this field can be done because of already existing previous research results which exist especially in the context of software development [32]. The ideas and approaches can be adopted for these application. A prerequisite for performing a validation is the integration of the MAS into the LUPO simulation environment. The challenge consists in the determination and collection of the relevant data for the indicators.

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