

AMOR – An Agent for Assisting Monitoring, Optimization and (Re-)Design in Factory Design

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Abstract

Within the new paradigm “Factory as Product”, three essential activities are of major interest. This paper investigates and answers the question how Monitoring, Optimization and (Re-)Design can be linked and supported. Based on the feedback control theory, an agent for assisting the essential activities is proposed and its tasks are described.

Keywords:

Factory Design, Factory as Product, Control Theory, Digital Factory

1 INTRODUCTION

The industrialization established mass production up to now. By this, the product and the factory producing it are connected and bidirectional constrained. In the past decades, the efficiency in product design was significantly improved by the introduction of IT tools. The so-called Digital Product represents the Real Product by data typically managed in a PDM System. The Digital Product allows a Monitoring of relevant product properties without investigating the Real Product. Furthermore, it is possible to improve the Real Product by optimizing and/or (re-)designing the Digital Product without building real prototypes.

Recently, a new paradigm emerged. This paradigm proposes to approach and understand today's factories as a new and complex type of product [1]. Subsequently, the Digital Factory emerged which is a digital representation of a Real Factory. Analogue to the product development, typical activities such as Monitoring, Optimization and (Re-)Design gain from the Digital Factory: Monitoring the Digital Factory enables Optimization and/or (Re-)Design either virtually, before the Real Factory exists, or directly on the Real Factory.

Developing a factory is currently enhanced thanks to the new paradigm “Factory as Product”, because mature design methods/approaches and concepts from product engineering are applied and transferred to factory design as exemplified in [2].

2 RELATED WORK

Today, lots of activities in a factory are supported by information technology. Unfortunately, most of the data is widely spread and distributed in many different systems [3]. Interfaces are often missing and the transfer of data has to be done manually. The realization of a full and working integration of all data, information and processes of a factory is seen to be relevant for staying competitive in the future. The idea of having a virtual and thus Digital Factory which is a representation of an existing factory was described in [4]. Recently, efforts to fully represent the factory and its products digitally and also virtually emerged [5] [6].

Based upon this full digital representation, computer supported controlling and optimization becomes more feasible. Additionally the interdependent planning and design processes of the factory and its products have to be coordinated and synchronized in order to get more agile and to swiftly respond to the fast changing market conditions [3].

It's obvious that one needs to know about the impact of optimizations and market-responding adoptions – either on the product, the factory, or on both. Therefore, the performance has to be measured and quantified. This is done by using so-called performance indicators (PIs) which rely on performance measuring systems that are again based on traditional accounting systems to monitor and improve operations [7].

In this context, the idea of a factory cockpit aiming at unerring decision making, improvement of daily load planning, acceleration of factory planning and a higher quality of planning results was addressed in the past [8].

3 FEEDBACK-LOOP BASED PERFORMANCE MEASUREMENT

By measuring the performance through an adequate performance measurement system, which focuses on the needs of product and factory design [9][10], the factory's management receives information on the relevant performance drivers of their company. This will support them by making efficient and effective decisions on changes in the product range and/or factory processes.

The obtained values of the performance indicators (PIs) enable a significant comparison of different change scenarios against adequate criteria. Last but not least, the verification and the grade of the target achievement can be observed and thus will provide a valuable feedback and input for the efforts of the continuous improvement processes which are well established in excellent leading companies as proposed by [11].

One can distinguish between establishing a regular control or one based on a feedback loop. Since the latter one takes previous measures into account, it enables a careful regulation and thus prevents overshooting. Hence, it is seen as straightforward to handle the provided feedback as an input and to set up a control loop as a measurement system. This yields a lot of other advantages. At first, a loop-based approach is in line with iterative processes that aim at higher quality or efficiency e.g. the idea of continuous improvement or the Six Sigma approach. Furthermore, an incremental approach does not need to be triggered by someone, since it

is meant to be persistent. Also the permanent adjustment between reference and measured values supports a better synchronization of control unit and the system itself.

Thus the performance measurement system presented in this paper proposes to be adequate for product and factory design and is approached by the analogy to the feedback control theory [12] (Figure 1).

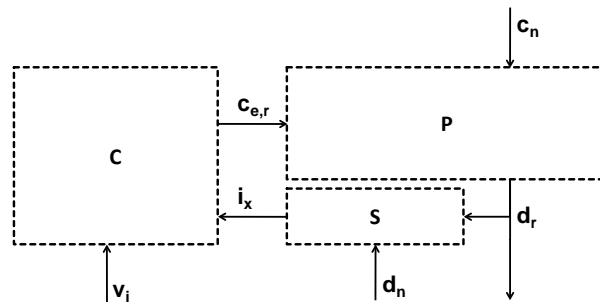


Figure 1: Basic feedback loop based on [12]

The feedback loop has three components: 'P' is the object to be controlled (the so-called plant), 'S' is a sensor that measures the plant's output, and 'C' is the controller, which generates the plant's input. Each of the three components has two inputs, one internal and one from outside the system. Every component has one output. The inputs and outputs are as follows:

- v_i reference or command input
- i_x sensor output
- $c_{e,r}$ actuating signal, input to 'P'
- c_n external disturbance
- d_r plant output and measured signal
- d_n sensor noise

According to [12], the variety of the performance activities can be summarized by approximating d_r as a predefined function of v_i in consideration of c_n and d_n which both reflect the uncertainty in the plant. Obviously, the performance objectives are described by the measurement i_x rather than d_r since often the only knowledge of d_r is obtained from i_x .

4 ESSENTIAL ACTIVITIES IN FACTORY DESIGN

As described in section 1, a production system (also: a factory) may be seen as a new kind of high complex product. Since its life cycle is based on a very long time frame, it has to be permanently adapted in order to respond to the continuously changing requirements and expectations from its environment. Thus, changes are normal and continuous at all levels [13] and should be supported as much as possible.

Furthermore, factories need to know their performance. By the aid of the PIs, the factory's management receives needed measures of the performance drivers of their company in order to make efficient and

effective decisions. In addition, the measured PI values allow the verification and the rate of the target achievement. This in turn requires the possibility to observe and visualize the PIs in order to evaluate the current state, to analyze problems, and to identify possible improvements. As stated in section 1, there exist three essential activities that have to be performed and hence need to be supported by tools. These essential activities are named Monitoring, Optimization, and (Re-)Design (the M, O and R in AMOR).

Monitoring is about gathering data and information about the current situation. Questions about the actual performance or whether goals are about to be achieved can be answered by that. Therefore, relevant data has to be collected. Then, the collected data has to be processed and evaluated so that relevant measures or indices can be continuously presented in the right form to the right audience. The proper definition of performance indicators is crucial for this activity. For example, to improve quality, the process improvement teams may select PIs such as defect rate, product return rate, rework rate or scrap rate [9].

While Monitoring has a real-time focus, Optimization operates on a tactical perspective. This includes small improvements or adaptations that help to increase effectiveness and efficiency that can then be measured by the performance indicators. The Optimization activity shall be performed whenever anything can be done better without much effort. Often, it is characteristic for Optimization that the performed actions are easily reversible, which implies that physical structures are not involved. For example, if the consumer demand rises, the tact rate could be increased.

Unlike the others, (Re-)Design has a more radical impact in general and a long-term strategic perspective. Resources, processes and tools are affected, as well as physical structures. (Re-)Design aims at a significant improvement in terms of the performance indicators and is often driven or forced by new emerging trends such as technology change, new products, industry and market growth or when other important boundary conditions have changed. (Re-)Design is a very crucial step that requires many monetary and non-monetary resources. In analogy to the previous example, if the consumer demand rises, another production line could be set up.

In order to provide a more formal definition of these three essential activities, a clear notation is given below which shall be consistently used in the remainder of this paper:

c_e evolutionary changes, e.g. "increase tact rate"

c_r revolutionary changes, e.g. "set up a production line"

i_x performance indicator (for a goal x), e.g. " $i_{\text{Quality}} = \text{defect rate}$ " [9]

d_r real output data, e.g. "current tact rate"

Within the context of the real and the Digital Factory, Monitoring, Optimization and (Re-)Design are related as shown in Figure 2. All activities are described in analogy to a transformation function. This means that each activity transforms a specific input into a specific output. In Figure 2, these inputs and outputs are symbolized by an arrow that transports information according to the notation. Furthermore, boxes are

used to represent the three essential activities. It is easy to see that the arrows in Figure 2 are symmetric. This means that the main function of all activities stays the same for the Real Factory and for the Digital Factory.

Monitoring is the task that operates on information that comes directly from either the Real or the Digital Factory. Ideally, this type of information is equal to the real output data d_r that is generated by a factory. This information is then transformed into a pre-defined measure that is more suitable for the evaluation, supervision and the assessment of the data. Calculated values for performance indicators i_x are the output of Monitoring. Within the notation, the x may reflect a goal that may be pursued with the Monitoring of the corresponding performance indicator i_x .

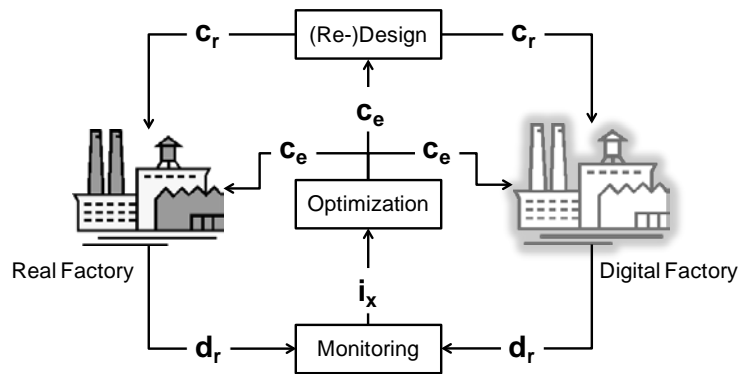


Figure 2: Essential activities in factory design

The Optimization activity's input is the output of Monitoring. Optimization aims at smaller changes that lead to improvements in terms of the performance indicators. In this way, Optimization may be interpreted as a transformation function that takes the information from the performance indicator values i_x and creates evolutionary changes c_e . Finally, (Re-)Design takes evolutionary changes c_e and transforms them into a revolutionary change c_r with a higher impact also on physical structures.

Although it is not explicitly depicted in Figure 2, there is a subset relation enclosed in the information flows which is expressed in equation 1. This is due to the fact that the activities do not consume the input information. Instead they create additional information that also includes the original input. Since i_x is derived from the real output data by calculation, d_r may be seen as included in i_x . Subsequently, this applies for c_e which includes i_x and correspondingly d_r . Also c_r includes c_e and thus the i_x and d_r information. Because the approach is incremental, it is also assumed that d_r at a specific time t also holds the information about c_r and c_e that were acquired earlier at $t-1$.

$$c_r(t) \supseteq c_e(t) \supseteq i_x(t) \supseteq d_r(t) \supseteq c_r(t-1) \supseteq c_e(t-1) \supseteq i_x(t-1) \supseteq d_r(t-1) \quad (1)$$

5 ASSISTING MONITORING, OPTIMIZATION AND (RE-)DESIGN

This section aims at integrating the advantages coming from a feedback-loop based approach while providing a support for the three essential activities. The goal is to find an answer to the question “How can Monitoring, Optimization and (Re-)Design be linked and supported?” which can be refined by four sub-questions. These questions face the most urgent and unclear aspects related to these activities and thus help to identify aspects for assisting Monitoring, Optimization and (Re-)Design.

- What does the measured performance of my factory mean today?
- When to perform an Optimization and when to perform a (Re-)Design?
- Was the performed Optimization or (Re-)Design activity successful?
- What are good possibilities for Optimization and/or a (Re-)Design?

In this paper, AMOR (an Agent for Assisting Monitoring, Optimization and (Re-)Design) is proposed that shall give an answer the above questions whenever they are needed in the context of factory design. In analogy to section 3, the proposed agent (the A in AMOR) shall act as a controller on the factory as shown in Figure 3. The following notation is used:

c_n exogenous disturbances / changes (noise)

e_c evaluation of the impact of a change

v_i reference values for the performance indicators

d_s sensed / measured data

d_p prediction data

d_n exogenous sensor input / data (noise)

Whereas the previous given symbols are all time-dependent and thus represent functions of time, two more symbols have to be introduced that are referring to certain points in time.

t_o trigger / time for performing an Optimization

t_r trigger / time for performing a (Re-)Design

As depicted in Figure 3, Optimization and (Re-)Design are seen as actuators that act on a factory and Monitoring is interpreted as a sensor that captures data from the factory to be controlled. In this context, it is important to note that the term factory is equally referring to the Digital Factory and the Real Factory, since their relations to Monitoring, Optimization and (Re-)Design are symmetric (see Figure 2).

The first question that has to be answered focuses on the aspect that everything can be measured, but the results have no meaning until they cannot be interpreted and compared. Furthermore, results which were interpreted as good some years ago may now be rather bad. Thus, asking for help in interpreting and evaluating the measured performance of a factory is obvious. This task is named **PI-Dynamization**, which means that the reference values v_i have to be dynamically adapted based on the observed values for the performance indicators i_x and assuming a continuous improvement. Also prediction data d_p that aims at forecasting environmental changes and particular events has to be regarded when adapting the reference values v_i .

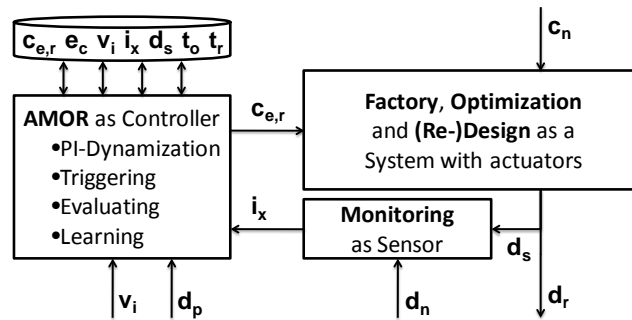


Figure 3: Assisting Monitoring, Optimization and (Re-)Design

The second question, and thus the second task for the prospective agent is named **Triggering** and aims at determining certain points in time when an Optimization (i.e. an evolutionary change c_e) or a (Re-) Design (i.e. a revolutionary change c_r) shall be performed and thus triggered accordingly. Therefore, the prediction data d_p plays a crucial role and if possible the expected impact of having revolutionary changes c_r or evolutionary changes c_e has to be assessed.

A main advantage of establishing a feedback loop as proposed in Figure 3 is to evaluate the impact of changes. Thus, **Evaluating** addresses the third question and is seen as another task that is useful for assisting Monitoring, Optimization and (Re-)Design. This task comprises a mechanism for evaluating and quantifying the impact of evolutionary and revolutionary changes $c_{e,r}$ based on analyzing the performance indicators i_x before and after a change. This results in an evaluation of a change e_c that tells whether a change was successful. Besides, it can also be used to evaluate change scenarios. Additionally, the task of Evaluating sets the results from the Monitoring activity into relation by comparing the value of the performance indicators i_x with their actual reference values v_i .

The existence of a database is also an enabler for providing support regarding the fourth question, which asks for tracking the lessons learned from previous Optimizations and (Re-)Designs. In this way, multiple negative experiences shall be avoided and positive experiences be promoted. This task aims at **Learning** based on experiences made in the past. Therefore, the existing data about changes $c_{e,r}$ and their evaluation e_c have to be exploited and used as a basis for deriving and suggesting promising changes to perform in the future.

6 CONCLUSION

This paper analyzed three essential activities in the context of factory design and set them into relation by defining information-based flows between them and assigning them a transformation function. Based on this, the analogy to control theory has been established by linking today's state-of-art in performance measurement systems and the advantages of a basic feedback loop. Then the results were integrated and a new feedback-loop based agent was proposed for assisting Monitoring,

Optimization and (Re-)Design within the scope of factory design. Finally, a closer look on the agent led to a clear specification of the tasks that have to be handled. In the future, there will be work on how existing tools fit in the presented AMOR concept and which tools are missing.

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