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PERFORMANCE FACTORY – A NEW APPROACH OF PERFORMANCE ASSESSMENT FOR THE FACTORY OF THE FUTURE

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Abstract: *A novel performance measurement and assessment framework called Performance Factory (PerFact) developed to monitor the Factory of the Future is presented in this work. PerFact operates target-oriented towards the vision and mission of the company by connecting overall goals and major requirements with the Key Performance Indicators (KPIs) and their specific reference values. Within PerFact, the performance is measured on the manufactured products, the corresponding production processes, and the used resources. Furthermore, PerFact is able to monitor and assess the performance of both, real production and virtual production scenarios. Moreover, the measurement system is balanced; it assesses the performance of the factory considering all perspectives relevant for each specific case.*
Key words: Performance Indicator, Performance Factory, Factory of the Future, Strategic Factory Planning

1. INTRODUCTION

Today, manufacturing enterprises have to meet increasing global consumer demands for greener, more customized and higher quality products. Thus, a transition to a demand-driven industry with lower waste generation and energy consumption is needed, and often referred to as the "Factory of the Future". This transition causes the product development to be more complex and affects the development of the corresponding production processes and facilities. Therefore, the related strategic planning and decision making in the Factory of the Future have become more complex and need new measurement systems, based on adapted Performance Indicators (PIs). Referring to this need, a new measurement and assessment frame called Performance Factory (PerFact) is presented in this work.

2. RELATED WORK

In the past decades, manufacturing enterprises relied on performance measurement systems which were based on traditional accounting systems to monitor and improve their operations [[1]],[[2]]. According to [[3]], it has been shown that these systems do not cover the relevant performance issues of production. One significant limitation of traditional performance measurement systems is that they focus on controlling and reducing labour costs. However, labour cost currently constitute on average only 12%, while overhead comprises 50-55%, of the manufacturing costs. Furthermore, the traditional systems are static and do neither support the concepts of flexible lean production nor continuous improvement [[3]]. Gregory [[4]] concludes in his state-of-the-art analysis of performance measurement systems that there is a need for a novel system with process approach and with the capability of evolving with the company.
Moreover, the interdependent planning and design processes of the Factories of the Future and their products have to be coordinated and synchronized in order to get more agile and to swiftly respond to the fast changing market demands and

conditions. In addition, the factories need to know about the impact of these market-responding adoptions on their performance – either on the product, the factory or on both. Recently, efforts emerged to fully represent the factory and its products digitally and also virtually [5],[6]. Such a representation offers the advantage of being able to test the planned adaptations on the factory and/or its products virtually before realizing it. This enables the assessment of different change scenarios and thus to choose the most adequate one for being realized.

By measuring the performance through an adequate performance measurement system, which focuses on the needs of product and factory design [7],[8], the factory's management receives the needed 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, the product structure, and/or the factory processes (manufacturing, logistics and assembly). In addition, the measured PI values enable a significant comparison of different change scenarios against adequate criteria. Last but not least, the verification and the grade of the target achievement of the strategic planning 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 [9],[10].

3. ESSENTIAL ACTIVITIES ALONG THE FACTORY LIFE CYCLE

Nowadays, changes in factories are frequently and continuously implemented at all levels of the factory and corresponding decision making and execution should be supported as much as possible. As described in [11], there exist three essential activities in the context of factory planning. These essential activities are named Monitoring, Optimization, and (Re-) Design. Within the context of the

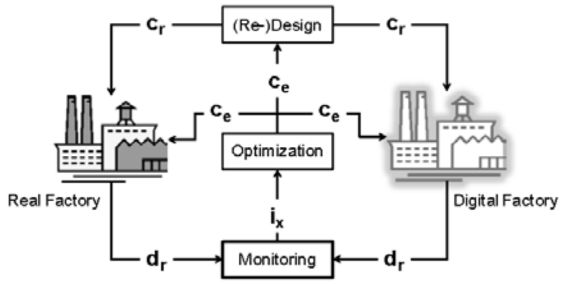

Fig. 1. Essential activities along the factory life cycle [11]

Real and the Digital Factory, Monitoring, Optimization and (Re-)Design are related as shown in Figure 1. All activities transform a specific input flow into a specific output flow. In Figure 1, these inputs and outputs are illustrated by an arrow which represents the transfer of information according to the following notation:

c_e - evolutionary changes
c_r - revolutionary changes
i_x - performance indication (for a goal x)
d_r - real output data from a factory

Furthermore, the three essential activities are represented by boxes. Moreover, the arrows in Figure 1 are symmetric. This indicates that the main function of all activities remain the same for both the real Factory and the Digital Factory.

Monitoring operates on data directly gathered from either the Real or the Digital Factory. Ideally, the Digital Factory is an accurate image of the Real Factory. Thus, the gathered information is equal to the real output data d_r that is generated by the real factory. In the following, this information is transformed into a pre-defined measure for certain goals – the calculated performance indicator values i_x – that is more suitable for the evaluation, supervision, and the assessment of the data. The Optimization activity's input is the output of Monitoring. Optimization aims at small improvements or adaptations that help to increase effectiveness and efficiency that finally can be measured by the performance indicators. In this way, Optimization may be interpreted as a transformation function that transforms the information from the performance indicator values i_x into the information of the evolutionary changes c_e. Finally, (Re-) Design takes the information about the evolutionary changes c_e and transforms it into revolutionary change information c_r. (Re-)Design has a very radical impact on the factory and aims at a significant improvement in terms of the performance indicators. Resources, processes and tools are affected, as well as physical structures. Within the context given by Figure 1, the Performance Factory represents a suitable method to support the Monitoring activity and is presented in the following.

4. THE PERFORMANCE FACTORY

PerFact is a novel holistic and balanced performance assessment system designed to monitor the Factory of the Future. It considers the consumer demands for greener, more customized and higher quality products and the related integrated product and factory design. Furthermore, it builds on the relevant issues of production since the performance calculation is based on the three main elements of currently deployed and established factory data models as already been used at Tecnomatix, Process Designer (Siemens PLM Software[1]) or Delmia (Dassault Systèmes[2]):

- manufactured products
- required processes
- related manufacturing resources or factory structures

The factory data model comprehensively describes the behaviour and status of a factory in various scales in order to represent a valid image for the Monitoring, Optimization and (Re-)design of the factory and its related processes [[12]]. This enables performance monitoring and assessment of running operation and planning scenarios as well. Furthermore, the performance assessments are dynamically supported by an agent based system in order to support the concepts of flexible lean production and continuous improvement as described in [[11]].

5. ARCHITECTURE OF THE PERFORMANCE FACTORY

The Performance Factory (PerFact) consists of a roof, several floors, pillars and a foundation as depicted in Figure 2. On the top of PerFact's architecture (within the roof), the vision and mission of the company is documented. All activities of the company are dedicated to these targets. Furthermore, the main strategic goals of the company are dedicated to the vision and mission. Underneath the roof – on the top floor – the major requirements and out of it the Key Performance Indicators (KPIs) are derived from the company's main strategic goals. It's envisioned to manage the major requirements and their relation to the KPIs with a formal model that has been proposed to manage functional product requirements [[13]]. One level below, the KPIs are divided into PIs and its related envisioned reference values are mapped. Moreover, a Perspective-pillar on the left hand side is arranging all available PIs according to different areas of development/growth like (customers, business, processes, finances, etc.). The reference values are directly connected to the shop floor of PerFact containing the PI Monitor. Within this central element, the comparison of the actually measured values with the reference values of the PIs is interpreted and visualised. The presented result enables the monitoring and assessment of the factory's performance. All dependencies between the PIs are formalized and accessible through a PI Ontology-pillar at the very left side. The values displayed by the PI Monitor are based on the PI Calculation situated at the foundation of PerFact's architecture. Here, the actual values of the PIs are calculated according to this PI Ontology and with

[1] http://www.plm.automation.siemens.com/en_us/products/tecnomatix/
[2] http://www.3ds.com/products/delmia/welcome/

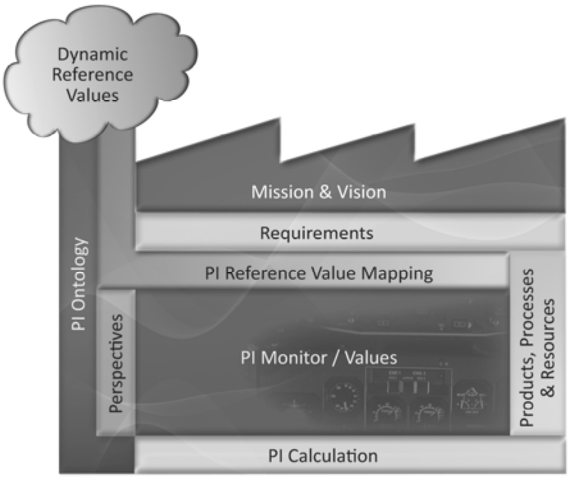

Fig. 2. The Performance Factory (PerFact)

regard to Product, Process and Resource (PPR) data. This PPR data is represented by another pillar on the right which is either retrieving real data from the ongoing production or virtual data from a simulation.

In the context of the three essential activities to be performed along the factory life cycle (Figure 1), PerFact is considered to assist the Monitoring. The output data from the real factory (d_r) are the input to the PPR factory data model in PerFact (pillar Products, Processes & Resources) and thus to the PI Calculation. The output flow of the Monitoring (i_x performance indication) is visualized in the PI Monitor of PerFact.

6. APPLICATION EXAMPLE OF THE PERFORMANCE FACTORY

In this paragraph, an example of a possible application of PerFact is presented in order to describe its utility pattern and related structured course of action. The described beverage company, all assumptions and statements in this paragraph are imaginary.

The course of action is divided into seven steps. The first three steps (1-3) belong to the strategic level, the following three steps (4-6) to the operational level and the last step (7) to the tactical level of the presented exemplary company.

Step 1: Definition of the *Mission & Vision* whereas the mission of a company represents its external and the vision its internal goal. The mission of the fictitious beverage company is "to supply the beverage to all persons worldwide at an affordable price". The vision is "to establish a global market share of 30% in the next ten years".

Step 2: Definition of the *Requirements*. This step includes the detailing of the mission and vision into strategic targets (2a) and the refinement from the strategic targets to the requirements (2b). The requirements on the lowest level finally represent the Key Performance Indicators (KPIs) (2c). In order to achieve a better differentiation, easier retrieval and simplified handling and description, the KPIs should be consequently rephrased into headwords. The strategic targets for the beverage company are (2a):

2.1 To produce cost-efficient and identically tasting batches at a constant quality level

2.2 To enter fast the big markets by rapidly building-up the production network.

Subsequently these two strategic targets may be refined into related requirements as follows (2b):

2.1.1 To ensure globally the established product quality standard

2.1.2 To offer the product at a reasonable price

2.2.1 To build-up quickly the production site

Since the requirements are not further detailed, the corresponding headwords for the KPIs are (2c):

2.1.1 Product Quality

2.1.2 Product Price

2.2.1 Ramp-Up Time

Step 3: Includes the definition of the *Perspectives* (3a) and the *PI Reference Value Mapping* (3b and 3c). Analogue to the concept of the Balanced Scorecard [2], the perspectives represent the main areas of development/growth of the factory. The perspectives in this example have been chosen as (3a):

3.1 Production
3.2 Sales
The final task of the strategic level is the mapping of the PI (3b) and its related reference values (3c): The already defined KPIs and the perspectives form a matrix whereas the KPI are represented in the columns and the perspectives in the rows (Table 1). Every single KPI represents an n-tuple whereas n equals the number of perspectives. Furthermore, a KPI consists of in maximum one tuple-PI for every perspective. In general we denote the name for as specific performance indicator as PI(KPI|Perspective).
As soon as a specific PI is determined, its corresponding reference value has to be set in a next step. This value is defined by the top management. Thus, for the beverage company example we get the following PIs and reference values:
PI(Product Quality|Production) = Process Capability Index (Cp) ≥ 2
PI(Product Quality|Sales) = Customer satisfaction (J.D. Power Index) > 80%
PI(Ramp-Up Time|Production) = Start of production (SOP) < 9 month
PI(Ramp-Up Time|Sales) = {}
Figure 3 shows the definition of KPIs, PIs, Perspectives and Reference Values after step 3.

KPIs / Perspectives	2.1.1 Product Quality	2.2.1 Ramp-Up Time	...
3.1 Production	Process Capability Index (Cp) = 2.0	Start of production (SOP) < 9 month	
3.2 Sales	Customer satisfaction, J.D. Power Index > 80%	–	
...			

Fig. 3. Example of the PI Matrix

<u>Step 4:</u> From the *Products, Processes & Resources (PPR)*, the current values of the PI are measured by sensors, simulation, etc. In this example this would be the amount of non-conformant batches, the amount of customer complaints, the calendar date and so on.
<u>Step 5:</u> *PI Calculation* for the PI defined in step 3. The calculation is performed according to formulas and knowledge stored in the *PI Ontology* and uses the *PPR*-data of step 4. As an example, the formula related to the PI "SOP" = date start of production – project start date.
<u>Step 6:</u> In the *PI Monitor*, the reference values (defined in step 3) are compared with the calculated actual values (step 5) and the result is visualized. For example, if the difference from the reference value and the actual value of the PI "SOP" is smaller than 9 month, the signal will be green; if it is 9 month, the signal will be yellow and if it is more than 9 months, the signal will be red.
<u>Step 7:</u> The *Dynamic Reference Values* represent a future-oriented planning tool. Within this element, the performance assessments are dynamically adapted in order to support the concept of continuous improvement which foresees an increase of the performance in the long term. Therefore, the reference values will be periodically adapted to the already achieved performance by using historical PI values. As example the reference values of the PI "Cp" may evolve in the following way: Cp ≥ 1.66 in 2000, Cp ≥ 2.0 in 2010 and Cp ≥ 2.33 in 2020.

7. CONCLUSION

PerFact represents a holistic performance measurement system, which monitors the factory with respect to the manufactured products, production processes and used resources. Furthermore, the measurement system is balanced and user group specific; it assesses the performance of the factory considering various perspectives and needs. Moreover, PerFact operates target-oriented towards the vision and mission of the company by connecting the overall vision and its derived major requirements with the KPIs and their specific reference values. Finally, PerFact is able to monitor and assess the performance of both real production and production scenarios.
In the future, there will be further research and detailing of the elements of PerFact. In this context, further works were released recently [[14]],[[15]]. In addition, PerFact will

be an integral element of AMOR [11] which is an agent based assistant system for the three essential activities performed along the factory life cycle.

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