Performance Factory – a new approach of performance assessment for the Factory of the Future

Journal Article

Author(s):
Jufer, Noëlle; Politze, Daniel P.; Bathelt, Jens; Kunz, Andreas

Publication date:
2012

Permanent link:
https://doi.org/10.3929/ethz-a-007135629

Originally published in:
Estonian Journal of Engineering 18(1), https://doi.org/10.3176/eng.2012.1.04

Funding acknowledgement:
247277 - Automated Urban Parking and Driving (EC)

Estonian Journal of Engineering, 2012, **18**, 1, 42–57 doi: 10.3176/eng.2012.1.04

Performance Factory – a new approach of performance assessment for the Factory of the Future

Noëlle Jufer[a], Daniel Patrick Politze[a], Jens Bathelt[b] and Andreas Kunz[a]

[a] Institute of Machine Tools and Manufacturing, Swiss Federal Institute of Technology, ETH Zurich, Tannenstrasse 3, 8092 Zurich, Switzerland; {jufer, politze, kunz}@iwf.mavt.ethz.ch
[b] Nova Innovation Solutions GmbH, Obstgartenstrasse 36, 8006 Zürich, Switzerland; bathelt@nova-innovation.com

Received 4 March 2011, in revised form 4 November 2011

Abstract. Factories of the Future have to be flexible, adaptable and committed to shorter product life-cycles and varying demand patterns in order to be competitive. Thus, three essential activities – Monitoring, Optimization and (Re-)Design – are seen to become even more important and shall be supported. This work focuses on the Monitoring activity which aims at assessing the current performance of a factory. Monitoring activity is seen as a basis for strategic planning and decision making in the Factory of the Future. Unfortunately, traditional performance assessment approaches neither sufficiently consider the data related to flexible production nor provide enough support for their specific needs. Referring to this need, a new measurement and assessment framework, called Performance Factory (PerFact) and its current implementation state, is presented in this work. In addition, the Virtual Factory Framework Project (VFF) is presented. VFF is in line with the concept of the Factory of the Future and envisions the development of a Virtual Factory in order to support and improve the real factory. This in turn allows and promotes the application of PerFact by selectively assessing the real performance or the performance of planning scenarios.

Key words: performance indicator, monitoring, Factory of the Future, strategic factory planning, Performance Factory.

1. INTRODUCTION

Today, manufacturing enterprises have to meet increasing global consumer demands for greener, more customized and higher quality products. Thus, a transition from traditional to demand-driven manufacturing with lower waste generation and energy consumption is needed, and often referred to as the "Factory of the Future" (FoF). 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 even more difficult and need new and adequate measurement systems, to monitor and assess performance.

In Section 2, the Factory of the Future is described according to literature and a Virtual Factory Framework (VFF) is presented, which is a specific approach of supporting and improving future factories. VFF is developed within an ongoing research project. Section 3 deals with related work concerning performance assessments and highlights requirements on performance measurement systems related to future factories. Important activities in factory planning and management including the Virtual Factory Framework and a concept to support these activities are presented in Section 4. In Section 5, PerFact, a new measurement and assessment framework is presented. Section 6 concludes the findings of this work.

2. FACTORY OF THE FUTURE

2.1. General description of the Factory of the Future

The development of a factory usually follows both the requirements of markets and products and the related adaptation of the resources [1]. It can be observed today that the product life cycle time is constantly decreasing and resources are changing frequently [1]. Moreover, a strong trend towards individualization of products can be observed [2]. This evokes the system "factory" to be continuously adapted to the requirements of new products and changed resources in order to realize economic benefit and to remain successful in the highly competitive and fast changing globalized markets [3]. Therefore, it must be a major strategic goal of the enterprise's management to develop future factories in order to be flexible, adaptable and committed to shorter product life-cycles and varying demand patterns [4]. Within this context, the main additional properties describing a FoF are the following [5]:

- Customer-oriented manufacturing
- Exploitation of identified technical potential to achieve high performance
- Increased efficiency of all resources
- Exploitation of identified human potential, skills and knowledge

Customer-oriented manufacturing focuses on the ability of producing and offering large number of products, which are sustainable and of high value in the same time frame in order to closely meet customer's requirements. Technical potential to achieve high performance is mainly seen in information and communication technology (ICT) enabled intelligent manufacturing – in process automation and optimization [6] as well as in exploiting new materials [7]. Increasing the efficiency of all resources is in accordance with more sustainable and more ecological manufacturing [7]. This, in turn, is expected to simultaneously increase the economic benefit. The new structures of a FoF – derived from the new strategic direction and goals described before – evoke changes both in the role of all personnel, from operator level to management, and in the relationships between suppliers and customers. Therefore, human skills to deal with the new situation have to be raised and human potential effectively exploited. New forms of business strategies, enterprise organizations and business models have to be developed and shared among all stakeholders. In a FoF, knowledge is highly integrated and processed on behalf of well-organized knowledge bases [8]. New network- and web-based technologies allow using and sharing knowledge worldwide, which eases collaboration between different business areas and also among geographically distributed partners and stakeholders. The extensive application of ICT tools, which support most business processes in the FoF, generate data that can be used, stored and reused in terms of continuous improvement processes and learning from former experience. Furthermore, storage of job information from business and production processes on a regular basis is assumed to facilitate performance assessments [9]. According to literature [4–9], factories which are developed to fulfill at least some of the above named requirements are called Factories of the Future.

2.2. Virtual Factory Framework

The Virtual Factory Framework, which is part of the European Commission Seventh Framework Programme (FP7), aims to promote major time and cost savings while increasing performance in the design, management, evaluation and reconfiguration of new or existing factories by further development and application of the concept of the Virtual Factory [10]. To reach this target, VFF provides the capability to simulate dynamic complex behaviour by using a new conceptual framework, designed to implement the next generation Virtual Factory, constantly synchronized with the Real Factory (Fig. 1). VFF focuses on implementing this framework for an object-oriented collaborative virtualized environment, representing a variety of factory activities meant to facilitate the sharing of product, process and resource information and knowledge. Thus, VFF represents a holistic and robust model. This requires the capability to simulate dynamic complex behaviour over the entire life cycle of the factory, which in itself is considered as a complex and long-living product [11] and provides an advanced planning, management and decision support as well as validation capability [12].

The VFF framework for the envisioned next generation Virtual Factory is based on the following four pillars, which can be understood as sub-models of the VFF model [13]:

- *Pillar I – Development of a holistic data model and a non-deterministic and collaborative procedure for factory planning and management*
  One planned outcome is a holistic factory data model for products, processes and resources (PPR).
- *Pillar II – Development of the VF manager*
  The VF manager model is intended to manage the data of each element of the manufacturing environment as well as the relations between the elements,

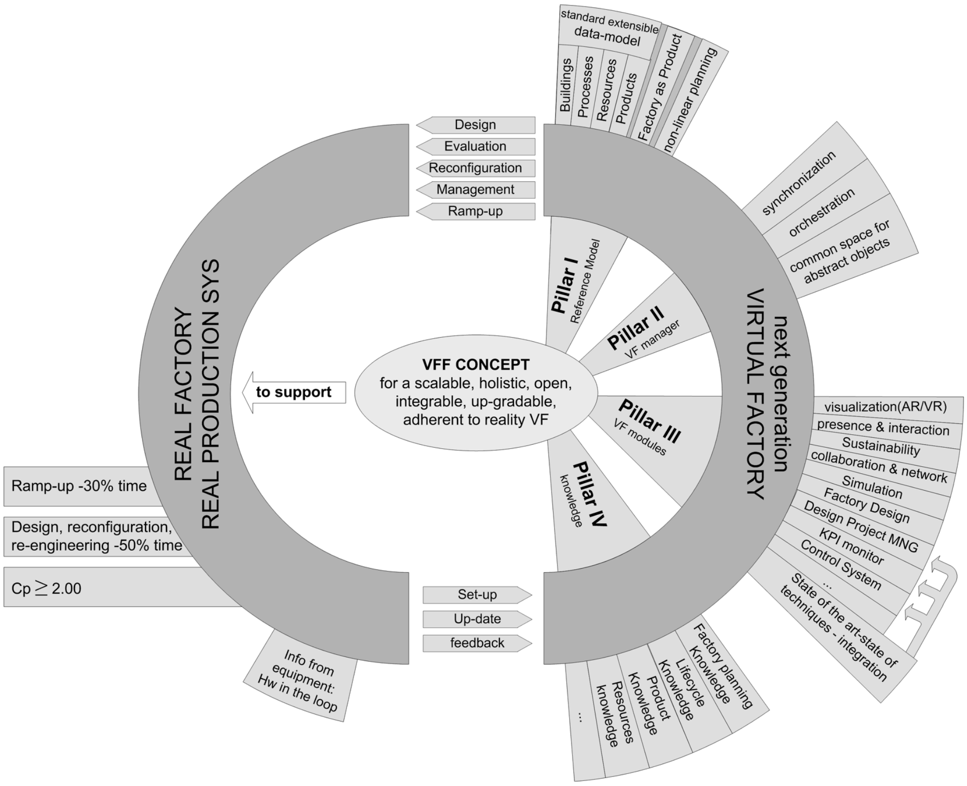


Fig. 1. VFF project concept [10].

guaranteeing data consistency and availability to any functional module. This enables collaboration between both different business areas and geographically distributed partners, teams, suppliers and all other stakeholders.

- *Pillar III – Development of the decoupled functional modules*
  Expected results in the VFF project are collaborative software tools supporting cost-effective and rapid creation, management and use of complex knowledge-based FoFs.
- *Pillar IV – Development of the knowledge repository and good practice*
  In this pillar, the knowledge related to the manufacturing enterprise will be formalized, stored and provided to the stakeholders in an appropriate format. The knowledge repository will include new business models and strategies for demand-driven sustainable industries. Moreover the stored data is prepared for reuse in continuous improvement activities. Storage of job information on a regular basis will support the monitoring activities in factory planning and management.

3. PERFORMANCE ASSESSMENT

In the past decades, manufacturing enterprises relied on performance measurement systems, which were based on traditional accounting systems to monitor and improve their operations [14,15]. According to [16], 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 only on controlling and reducing labor costs. However, labor cost currently constitute on average only 12% while overhead constitutes 50%–55% of the manufacturing costs. Furthermore, the traditional systems are static and do not support neither the concepts of flexible lean production nor continuous improvement [16]. Gregory [17] concludes in his state-of-the-art analysis of performance measurement systems that there is a need for a novel operations-based system, which has 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 make them more agile as well as swiftly respond to the fast changing market demands and conditions [18]. 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 [11,19]. 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 to choose the most relevant one for further realization.

By measuring the performance through an adequate performance measurement system (based on a network of Performance Indicators, PIs), which focuses on the needs of product and factory design [20,21], the factory's management receives much 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 factory processes (manufacturing, logistics and assembly), and the application of resources. In addition, the measured values of the PIs enable a significant comparison of different change scenarios against relevant criteria. Last but not least, the verification and the grade of the target achievement can be observed and thus will provide valuable feedback and input to the continuous improvement processes, which are well established in excellent leading companies [22,23].

The novel performance measurement and assessment framework PerFact, presented in Section 5, considers the above requested elements. In PerFact, the PIs values can be measured on Real or Virtual production processes, considering synchronized product and factory data, based on enhanced ICT systems or highly integrated, synchronized and well-organized knowledge bases. Thus, PerFact is able to monitor and assess the performance of both operative production and production scenarios. Based on the idea to additionally assess planning scenarios with the PerFact framework, the improvements on performance, e.g. by introducing lean philosophy, can be compared to the current state without lean concept introduction. Moreover, PerFact operates in a target-oriented manner towards the vision and mission of the company with respect to the individual goals of several stakeholders. This is done by connecting the overall vision and derived major requirements with the PIs and their specific reference values. In PerFact, this connection is also supposed to be documented and visualized, thus knowledge of the company's strategy and business objectives can be shared among both different business areas and hierarchy levels.

4. FACTORY PLANNING AND MANAGEMENT

Due to the fast changing markets and the shorter product life cycles, changes in factories are frequently and continuously implemented at all the factory's levels as well as in the corresponding decision making and execution processes. According to [24], three essential activities can be identified and seek for strong support in the context of factory planning and management (Fig. 2). These essential activities are named Monitoring, Optimization, and (Re-)Design. Within the context of the FoF, a promising approach to support these essential activities is provided by the concept of the Virtual Factory [13]. This concept includes a digital representation of the physically existing factory – in the following named Real Factory – which is synchronized with its digital representation, the Virtual Factory. The synchronization assures the accuracy of the digital representation all along the factory life cycle. In the Virtual Factory, planning and/or change scenarios can be tested and evaluated with much lower cost and time efforts as compared to testing in the Real Factory. Subsequently, the best planning or change scenario can be implemented in the Real Factory while its digital representation is adapted simultaneously.

Monitoring operates on information that comes directly from either the Real or the Virtual Factory (d_r). This information is then transformed into a pre-

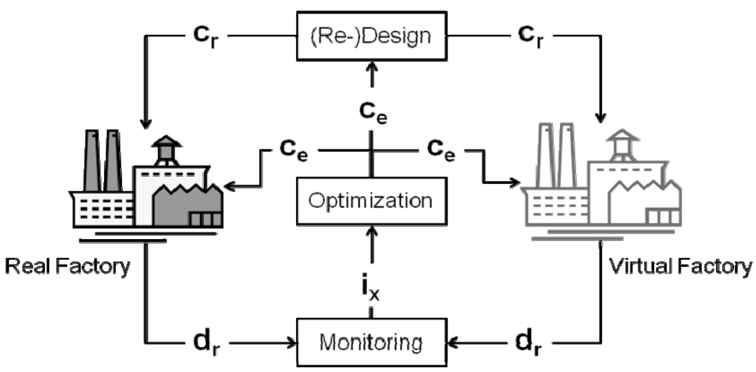


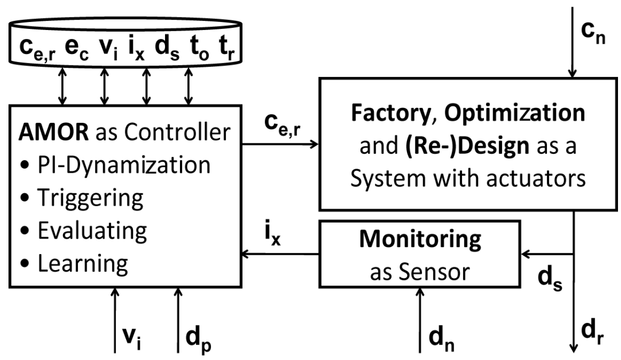
Fig. 2. Essential activities in factory planning and management, based on [24].

defined measure that is more suitable for the evaluation, supervision and the assessment of data.

Calculated values for Performance Indicators and Key Performance Indicators (KPIs) are the output of Monitoring. The Optimization activity's input is the output of monitoring. Optimization aims for smaller changes that lead to improvements in terms of the KPIs and PIs. In this way, Optimization may be interpreted as a transformation function that takes the information from the KPI/PI values and creates evolutionary changes of the Real or Virtual Factory. Finally, (Re-)Design takes evolutionary changes and transforms them into a revolutionary change with a higher impact also on physical structures.

In [24], it is proposed to support Monitoring, Optimization and (Re-Design) by a knowledge-based agent – Agent for Assisting Monitoring, Optimization and (Re-)Design (AMOR) – and to establish a control loop between these activities as shown in Fig. 2.

As depicted in Fig. 3, Optimization and (Re-)Design are seen as actuators that act on the Real or Virtual Factory. Monitoring is interpreted as a sensor that captures data from the Real or Virtual Factory to be controlled. The AMOR concept is included in the PerFact framework which is described in the following. More detailed information on the AMOR concept can be found in [24].



c_n	exogenous disturbances / changes
$c_{e,r}$	(r)evolutionary changes
d_r	real output data
i_x	performance indicator (for a goal x)
e_c	evaluation of the impact of a change
v_i	reference values for the PIs
d_s	sensed / measured data
d_p	prediction data
d_n	exogenous sensor input / data
t_o	trigger for performing an Optimization
t_r	trigger for performing a (Re-)Design

Fig. 3. AMOR control loop [24].

5. THE PERFORMANCE FACTORY

5.1. Description of the Performance Factory

The Performance Factory (PerFact) is a novel holistic and balanced performance assessment framework designed to monitor the planning and management of Factories of the Future. It considers the strategic and operational level and works target oriented towards the vision and mission of the company with respect to the individual goals of several stakeholders. Moreover, it builds on the relevant issues of production since the performance calculation is based on the three main elements (PPR) of currently deployed and established factory data models. A PPR data model is to be implemented in the VFF project and already used in Teamcenter (Siemens PLM Software[1]) or Enovia (Dassault Systèmes[2]):

- manufactured **P**roducts (P)
- required **P**rocesses (P)
- related manufacturing **R**esources or factory structures (R)

The factory data model comprehensively describes the behaviour and status of a factory in various scales in order to represent a valid image to support the Monitoring, Optimization and (Re-)Design of the Real and Virtual Factory and its related processes [25]. This enables performance monitoring and assessment of running operation and planning scenarios as well. Furthermore, the performance assessments are envisioned to be dynamically supported by an agent-based system, as conceived in AMOR (Fig. 3), in order to support the concepts of flexible lean production and continuous improvement as described in [24].

5.2. Architecture of the Performance Factory

The architectural scheme of PerFact is shaped as a factory and consists of a roof, several floors, pillars and a base as depicted in Fig. 4.

On the top of PerFact's architecture (within the roof), the *Mission and Vision* of the company is documented. The mission represents the company's external and the vision its internal goal. In VFF for example, the *Mission* is to provide a methodology to future factories which enables them to achieve major time and cost savings while simultaneously increasing performance in all their planning and management activities.

The *Vision* of VFF is to establish a new conceptual framework to implement the next generation Virtual Factory, which is constantly synchronized with the Real Factory and enables valuable decision support to all planning and management activities for the company. Subsequently, from the *Mission and Vision*, the company's strategy and from this the main strategic goals are derived.

---

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

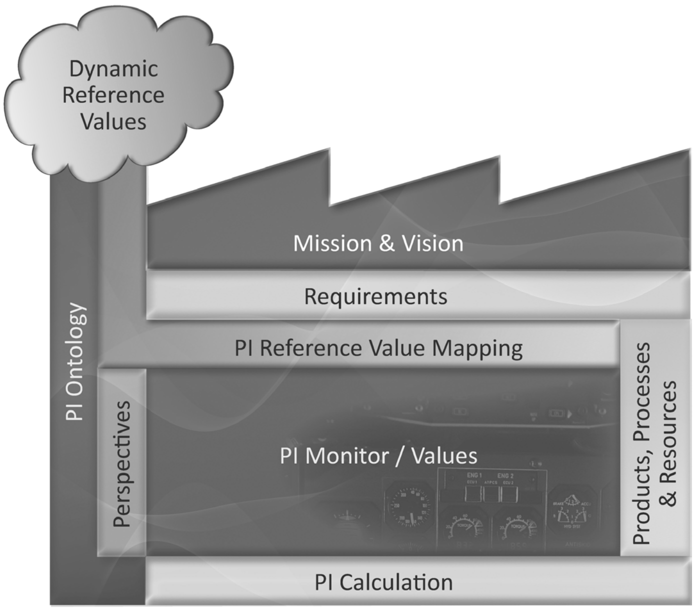


Fig. 4. The Performance Factory (PerFact).

Underneath the roof – on the top floor – the *Requirements* are defined. The *Requirements* together with their related targets *Reference Values* represent the goals of the company (Fig. 5). Starting from the main strategic goals, which were

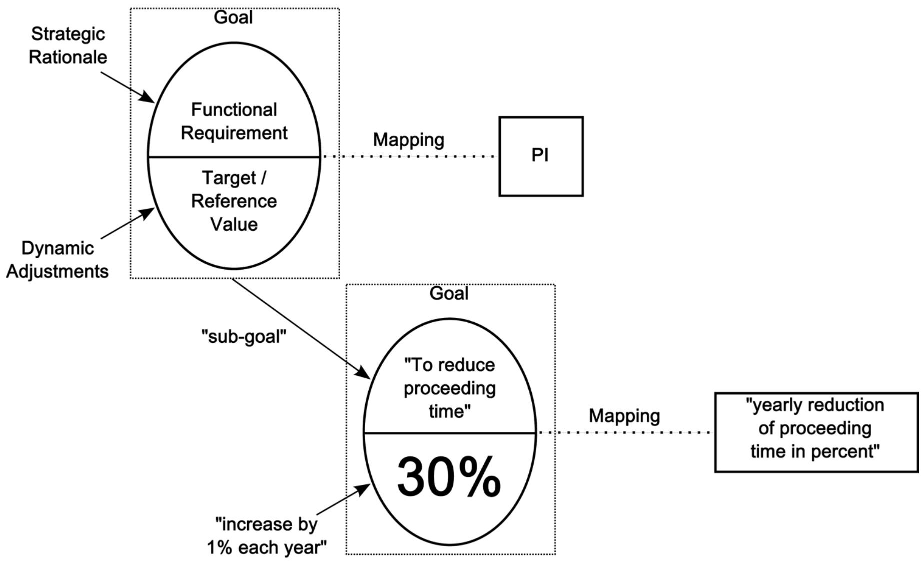


Fig. 5. Goal modelling according to the FOPD approach [26].

derived from the company's strategy as mentioned above, the main functional *Requirements* are defined by reformulating the goals in a functional manner. As the next step, these major *Requirements* can be decomposed and further refined in order to better describe the measures that shall be pursued, according to the strategic direction and needs of the company. The result of this process is a network, representing the company's *Requirements* and their relations and interdependencies amongst each other (Fig. 6, Goal/Requirement Layer). These *Requirements* have to be met in order to realize the strategy and to promote the company in the direction of the *Mission and Vision*.

The *PI Reference Value Mapping* area in PerFact enables monitoring of the target achievement by the *Mapping* of both Performance Indicators (PIs) as well as target *Reference Values* to all *Requirements*. As envisioned by the Function-Oriented Product Descriptions (FOPD) approach [[26]], Fig. 5 shows the general concept of the goal modelling in the upper part and a specific example in the context of VFF in the lower part.

As depicted in the upper part of Fig. 5, the modelling of the company's goals includes three elements: the formulation as "Functional Requirement", the defined "Target/Reference Value" and the mapped "PI". The "Functional Requirement" is derived from the "Strategic Rationale" of the company and closes the circle from the goals at each level to the *Mission and Vision* of the

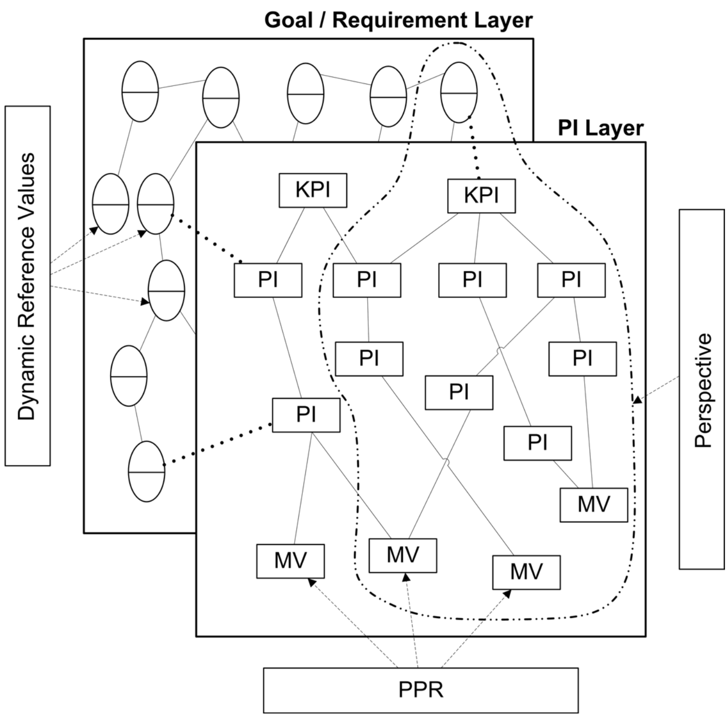


Fig. 6. Relation of the goal and measurement modelling.

company. The “Target/Reference Value” is a specific measure defined by the management, which indicates the intended grade of target achievement and assures its measurability. Moreover, the “Dynamic Adjustments” directly impact the “Target/Reference Value”. PerFact is intended to perform these adjustments automatically (*Dynamic Reference Values*) in order to establish a performance measurement system, which dynamically adapts to changes of the factory. Thanks to the mapping of the PIs, the actual performance, achieved in the Real or Virtual Factory, can be compared with the planned performance of the company. In PerFact, it is envisioned to manage the *Requirements* and their relation to the PIs with an extended version of a formal model that was proposed to manage functional product requirements [27].

The lower part of Fig. 5 provides an example in the context of VFF. One “Functional Requirement” of VFF can be “to reduce proceeding time”, which directly refers to VFF’s mission “to provide a methodology to future factories which enables them to achieve major time and cost savings…” as described before. The related reference value is “time reduction of 30%” and the mapped PI is “yearly reduction of proceeding time in percentage”.

Figure 5 presents the concept of goal modelling in PerFact, focused on one particular goal. As already mentioned, all the modelled goals together form a network as illustrated in Fig. 6.

In addition, the mapped PIs form another network, where the dependencies and interconnections are established by the formulas defined to calculate the PI values. These two networks are connected by the “PI Mapping”. In the “Goal/Requirement Layer”, the goal’s network – including the requirements and the target values – is shown. In the “PI Layer”, the PI network is presented. In Fig. 6, the PI network is further detailed showing two specific kinds of PIs: the Key Performance Indicators (KPIs) and Measured Values (MVs). The KPIs are PIs which are mapped to the main strategic Requirements and therefore are the most important PIs of the company. The MVs comply with the variable d_s “sensed/measured data” (Section 3) and are directly extracted from the *Products, Processes & Resources* (PPR) data. The MVs represent the input data used in the calculation of the PI values and form the connecting element between the factory data collected and the calculated performance values of the PIs. The MVs are the only kind of PIs which are not directly mapped to the goals.

As an example in the context of VFF, the PI “yearly reduction of proceeding time in percentage” can be a KPI since it directly refers to the mission as mentioned before. In VFF’s PI network for example, this KPI can be divided into the PIs “yearly reduction of proceeding time for factory design”, “process capability index (c_p)”, etc. The PI “yearly reduction of proceeding time for factory design” can be effectively measured using the related MVs “used time for the factory design process” and “mean used time for factory design in the past”.

Thanks to these two connected layers, a complete model of the target-system together with the chosen strategic measures and their mappings to the achieved measures from Virtual or Real Factory operation can be provided.

The elements of Fig. 6 are exemplified in the following picture, based on the results achieved in VFF [10]. The perspective, shown in Fig. 6, is implemented in VFF by the various stakeholders involved in factory design. As an example, the sustainability responsible is responsible for the functional requirement (FR) "To use CO_2 efficiently". All sustainability demands are grouped accordingly as sketched in Fig. 6. Furthermore, a PI can be assigned, as illustrated by the dotted line. In the example from Fig. 7, the PI EfficiencyPerCO_2 in conjunction with its formula and unit is connected to FR by exploiting an editable library. Each formula can be decomposed to MVs to be measured and extracted from the PPR data. Furthermore, every target value has a defined life time. In the example shown in Fig. 7, a yearly update is foreseen.

Although the net of KPIs, PIs and MVs is company-specific, since they are dependent on the defined strategy and strategic targets to fulfill the mission and vision, the authors aim at providing support to companies for the definition of the PI network on behalf of the *PI Ontology*, which is represented by a pillar at the very left side of PerFact (Fig. 6).

In the *PI Calculation* area, situated at the base plate of PerFact's architecture, the actual values of the Pis, according to the previously defined net of KPIs, PIs and MVs and the related formulas stored in the *PI Ontology* are calculated. As described above, the MVs are determined with regard to PPR data (*Products, Processes and Resources*). This PPR data is represented by another pillar on the right side of PerFact, which is either retrieving "Real" data from ongoing production or "Virtual" data from a simulation based digital representation of the production.

The shop floor of PerFact contains the *PI Monitor/Values*. Within this element, the strategic goals of the company are arranged and grouped according to different *Perspectives*, which represent the different areas of development/growth, defined by the company. These can be, for example, customer-oriented manufacturing processes, technical potential, efficiency of resources, stakeholders, finances, etc and are represented by a *Perspectives*-pillar on the left hand side of PerFact's architecture. Figure 6 shows the grouping of the goals and

FR	(K)PI name	Formula	Unit	Op (erator)	Target Value	Frequency	Start date	End date
To use CO_2 efficiently	Efficiency PerCO_2	Gross Value Added / CO_2 tons used	€/ t CO_2	<	3'873	Yearly	2010	2011

Fig. 7. Example of a specific relation between the goal and measurement model.

PIs to a *Perspective*. In addition, in the *PI Monitor/Values* area, the achieved performance of the company is presented. This can be realized by visualized relations and dependencies of the strategic goals and comparisons, interpretation and visualization of the calculated KPI/PI values and the related reference values, which are mapped to the goals. The presented results support the monitoring and assessment of the factory's performance in terms of visualizing the elements whether the targets are achieved or not.

The area of the *Dynamic Reference Values*, represented as a chimney on the top left side of PerFacts architecture, represents the envisioned functionality of PerFact to support the dynamic processes of factory planning and management. This implies automatically adaption of the *PI Reference Values* in terms of change activities along the factory life-cycle, for example, triggered by continuous improvement processes and/or adaptations to fast changing markets or changed resources.

More application examples of PerFact can be found in [[28–30]]. In addition, the PerFact framework was implemented in the context of three FP7 European Research Projects. In each project, specific sections and aspects of the PerFact framework were realized and validated by industry loops. In the project DOROTHY [[31]] a software tool – the Performance Indicator Calculator (PIC) – was developed to monitor PIs (direct cost and time) related to high variant production, whereas the needed input data to calculate the PI values was directly retrieved from PPR data [[32,33]]. The following sections of PerFact were exemplary addressed and implemented by PIC: *PI Monitor/Values*, *Product, Processes & Resources* and *PI Calculation*. The validation of the software tool was performed by two industry partners of DOROTHY: Hugo Boss and CTC. In the project VFF (cf. Section 2.2), a software tool – the Requirements Management and KPI Planning tool (RMP) – was developed [[34,35]]. RMP implemented the following sections of PerFact: *Mission & Vision*, *Requirements*, *PI Reference Value Mapping* and the *Dynamic Reference Values*. RMP was validated by three VFF industry partners: Homag, AutoEuropa and Ficep. Finally, in the project FoFdation [[36]] the concept of the *PI Ontology* was exploited for the *Perspective* "Sustainability" as exemplified in Fig. 7.

6. CONCLUSIONS

Based on the needs of the Factories of the Future, a new architectural scheme for the Monitoring task, called PerFact, has been presented. It has been explained how a suitable performance measurement system can be set up, which is able to monitor the entire factory with respect to the mission, vision, major requirements, products, corresponding production processes and used resources.

In the next step, the understanding of the Factory of the Future has been clarified, their needs have been outlined and the shortcomings of traditional performance measurement approach have been named. Based on that, the article presented how the use of Performance Indicators (PIs) contributes to a target-oriented performance measurement that simultaneously supports strategic planning and management activities for the Factories of the Future. In this context, the connection to a function-oriented goal modelling approach and its linkage to an interrelated net of KPIs, PIs and MVs has been explained.

Moreover, the proposed approach not only overcomes some of the shortcomings of traditional measurement systems, but also yields additional benefits.

Applied from the beginning of a new factory planning procedure, the proposed PerFact concept allows the creation of a corresponding factory measurement system right from the start, which results in time-savings and a perfectly tailored measurement system. Furthermore, the incorporation and connection to a framework for a Virtual Factory allows the assessment of different scenarios and thus may improve and ease decision-making processes.

Finally, it should be noted that PerFact is intended to be an integral element of AMOR by serving as a concrete method for supporting the Monitoring task in the scope of an ongoing Factory Planning procedure.

ACKNOWLEDGEMENT

The research reported in this paper has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement NMP2 2010-228595, Virtual Factory Framework (VFF).

REFERENCES

1. Leonard-Barton, D. Core capabilities and core rigidities: A paradox in managing new product development. *Strategic Manag. J.*, 1992, **13**, SI: Strategy Process, Managing Corporate Self-Renewal, 111–125.
2. Jiao, J., Zhang, L. and Pokharel, S. Process platform planning for variety coordination from design to production in mass customization manufacturing. *IEEE Trans. Eng. Manag.*, 2007, **54**, 112–129.
3. Bessey, E., Bueno, R., Decubber, C., Chlebus, E., Goericke, D., Groothedde, R., Hanisch, Ch., Jovane, F., Mendonca, J., Paci, A., Westkämper, E. and Williams, D. Research, technology and development for manufacturing. In *The ManuFuture Road – Towards Competitive and Sustainable High-Adding-Value Manufacturing* (Jovane, F., Westkämper, E. and Williams, D., eds). Springer-Verlag, Berlin, Heidelberg, 2009, 89–121.
4. Teresko, J. Planning the Factory of the Future. *Industry Week*, Factory Automation, 2008, Dec., 22–24. (http://www.industryweek.com/articles/planning_the_factory_of_the_future_17749.aspx, retrieved on November 4, 2011.)
5. Westkämper, E. The proactive initiative ManuFuture Roadmap. In *The ManuFuture Road – Towards Competitive and Sustainable High-Adding-Value Manufacturing* (Jovane, F., Westkämper, E. and Williams, D., eds). Springer-Verlag, Berlin, Heidelberg, 2009, 138–147.
6. Weimer, G. Factory of the Future? *Material Handling Manag.*, 2000, **55**, 28.
7. Sampson, B. Greener plants. *Profess. Eng.*, 2010, **23**, 19.
8. Welber, I. Factory of the Future. *IEEE Control Syst. Mag.*, 1987, **7**, 20.

9. Teresko, J. Preparing for the Factory of the Future. *Industry Week*, Factory Automation, 2007, Dec., 20–22. (http://www.industryweek.com/articles/preparing_for_the_factory_of_the_future_15330.aspx, retrieved on November 1, 2011.)
10. VFF, Holistic, extensible, scalable and standard Virtual Factory Framework. www.vff-project.eu/, (FP7-NMP-2008-3.4-1, 228595), 2009. (Retrieved on November 1, 2011.)
11. Pedrazzoli, P., Rovere, D., Constantinescu, C., Bathelt, J., Pappas, M., Dépincé, P., Chryssolouris, G., Boër, C. R. and Westkämper, E. High value adding VR tools for networked customer-driven factory. In *Proc. 4th International Conference on Digital Enterprise Technology*, *DET*. Bath, U.K., 2007, 347–352.
12. Jain, S., Choong, N. F., Aye, K. M. and Ming, L. Virtual Factory: an integrated approach to manufacturing system modeling. *Int. J. Operation Production Manag.*, 2001, **21**, 594–608.
13. Pedrazzoli, P., Sacco, M., Jönsson, A. and Boer, C. R. Virtual Factory Framework, Key enabler for future manufacturing. In *Digital Enterprise Technology* (Cunha, P. F., Maropoulos, P. G., eds). Springer, US, 2007, 83–90.
14. Jackson, P. The management of performance in the public sector. *Public Money and Management*, 1988, **8**, 11–16.
15. Kaplan, R. S. and Norton, D. The balanced scorecard: measures that drive performance. *Harvard Business Rev.*, 1992, **70**, 71–79.
16. Jarkon, J. G. The productivity paradox. *Business Week*, 1988, 100–108.
17. Gregory, M. J. Integrated performance measurement: a review of current practice and emerging trends. *Int. J. Production Econ.*, 1993, **30/31**, 281–296.
18. Weimer, T., Kapp, R., Klemm, P. and Westkämper, E. Integrated data management in factory planning and factory operation – an information model and its implementation. In *Proc. 41st CIRP Conference on Manufacturing Systems*. Tokyo, Japan, 2008.
19. Bacs, C. New datahandling and rapid virtual prototyping approach for mechatronic systems. In *Proc. 15th International Conference on Engineering Design ICED07*. Paris, 2007.
20. Ghalayini, A. M., Noble, J. S. and Crowe, T. J. An integrated dynamic performance measurement system for improving manufacturing competitiveness. *Int. J. Production Econ.*, 1997, **48**, 207–225.
21. Ahmad, M. and Dhafr, N. Establishing and improving manufacturing performance measures. *Robotics Computer Integr. Manufact.*, 2002, **18**, 171–176.
22. *EFQM Excellence Model* (European Foundation for Qualitiy Management). EFQM Publications, Brussels, 2003.
23. Aguayo, R. *Dr. Deming: The American Who Taught the Japanese About Quality*. Simon & Schuster, New York, 1990.
24. Politze, D. P., Jufer, N., Bathelt, J., Kunz, A. and Wegener, K. AMOR – an agent for assisting monitoring, optimization and (Re-)Design in Factory Design. In *Proc. 43st CIRP Conference on Manufacturing Systems*. Vienna, Austria, 2010.
25. Constantinescu, C. and Westkämper, E. Grid engineering for networked and multi-scale manufacturing. In *Proc. 41st CIRP Conference on Manufacturing Systems*. Tokyo, Japan, 2008.
26. Politze, D. P., Bathelt, J. and Wegener, K. Function-oriented product descriptions in product development and factory planning. In *Lecture Notes in Engineering and Computer Science: Proc. World Congress on Engineering and Computer Science*, *WCECS 2010*. San Francisco, USA, 2010, 1168–1172.
27. Politze, D. P. and Dierssen, S. A. Functional model for the functions oriented description of customer-related functions of high variant products. In *Proc. NordDesign*. Tallinn, Estonia, 2008.
28. Jufer, N., Politze, D. P., Bathelt, J. and Kunz, A. Performance Factory – A new approach of performance assessment for the Factory of the Future. In *Proc. 7th International DAAAM Baltic Conference "Industrial Engineering" (DAAAM10)*. Tallinn, Estonia, 2010.
29. Jufer, N., Daaboul, J., Bathelt, J., Politze, D. P., Laroche, F., Bernard, A. and Kunz, A. Performance factory in the context of mass customization. In *Proc. 16th International Conference on Concurrent Enterprising*. Lugano, Switzerland, 2010.

30. Bathelt, J., Politze, D. P., Jufer, N., Kunz, A. and Jönsson, A. Factory of the Future enabled by the Virtual Factory Framework. In *Proc. 7th International DAAAM Baltic Conference "Industrial Engineering" (DAAAM10)*. Tallinn, Estonia, 2010.
31. DOROTHY, Design of CustomeR dRiven ShOes and multi-siTe factorY. www.dorothy.ethz.ch (FP7-NMP-2007-4.3.3-1, 213180), 2008. (Retrieved on November 1, 2011.)
32. Pandremenos, J., Georgoulias, K., Chryssolouris, G., Jufer, N. and Bathelt, J. A shoe design support module towards Mass Customization. In *Proc. 16th International Conference on Concurrent Enterprising*. Lugano, Switzerland, 2010.
33. http://www.dorothy.ethz.ch/Newsletter/DorothyNews_02.pdf, page 7, 2010. (Retrieved on November 1, 2011).
34. Politze, D. *Strukturierung von Produktfunktionen auf Basis von Funktionsähnlich-keiten - Methodik zur Erstellung einer funktionsorientierten Erzeugnisgliederung*. PhD Thesis, ETH, Zurich, 2011.
35. http://www.vff-project.eu/?p=495, RMP: Requirements Management & KPI Planning, VFF News # 3, page 10, 2011. (Retrieved on November 1, 2011).
36. http://www.fofdation-project.eu/Pages/Default.aspx Retrieved on November 1, 2011.

Tulemuslik tootmisettevõte – uus lähenemine tuleviku tootmisettevõtte tegevustulemuste hindamiseks

Noëlle Jufer, Daniel Patrick Politze, Jens Bathelt ja Andreas Kunz

Tuleviku tootmisettevõtted peavad konkurentsivõime tagamiseks olema paindlikud, kohanduvad, suundumusega lühemale toote elutsüklile ja suutelised arvestama muutuva nõudlusega. Hinnanguliselt muutuvad kolm järgmist olulist tegevust – seire, optimeerimine ja (re)disain – üha tähtsamaks ning neid tuleb soodustada. Antud uurimuses on keskendutud tootmisettevõtte jooksvaid tulemusnäitajaid arvestuslike näitajatega võrdlevale seirele. Tuleviku tootmisettevõttes muutub strateegilisel planeerimisel ja otsuste vastuvõtmisel seire põhiliseks lähtealuseks. Kahjuks ei võimalda traditsioonilised lähenemised tulemuste hindamisel piisavalt arvestada paindtootmisest saadavate andmetega ega paku selle spetsiifilistele vajadustele piisavat tuge. Sellest vajadusest ajendatult on käesolevas uurimuses esitatud uus mõõte- ja hindamismetoodika "Tulemuslik tootmisettevõte" (PerFact) ning kirjeldatud selle rakendusvõimalusi. Lisaks on tutvustatud virtuaaltootmise arendusprojekti VFF. VFF on kooskõlas EL-i tuleviku tootmisettevõtete arengukontseptsiooniga ja näeb ette reaalse tootmisettevõtte toetamiseks ning parendamiseks vastava virtuaalse tootmisettevõtte arendamist. See omakorda võimaldab ja soodustab PerFacti rakendamist, kus hinnatakse valikuliselt tegelikke tulemusnäitajaid või arengustsenaariumide tulemusnäitajaid.