Classification of a Hybrid Production Infrastructure in a Learning Factory Morphology

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Abstract

Current market trends confront industrial production with significant challenges: Volatility increases, uncertainty mounts, complexity grows and ambiguity escalates. While flexible and changeable organizational structures sufficed to combat present-time increasingly dynamic demands, modern disruptive times call for agility.

Agile learning will require expedited and well-structured training within industrial organizations: Learning factories enable new technologies to be put on trial, they capacitate integrated work and learning environments and they provide a valuable framework to instruct and educate new employees.

Numerous existing learning factories are geared towards education in engineering and didactics of industrial production. Defined distinctions are yet to be thoroughly discussed and will further the evolution of terminology and good learning factory practices.

This article portrays various use cases from real manufacturing operations and their accompanying indirect processes within the Demonstration Factory on the RWTH Aachen Campus. These cases shall be assorted to relevant characteristics of a morphologic description model for learning factories presented by Abele et al. and derive a critical reflection and enhancement of this framework.

The applicability of said morphology shall be examined for the holistic Demonstration Factory approach with its aim to manufacture marketable goods in a genuine continuous industrial small batch production.

Keywords: Learning Factories; Learning Factory Morphology; Use Cases; Hybrid Production Infrastructure

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1. Introduction and Motivation

Challenges in production processes and the preceding engineering tasks [1] rise as new production technologies become available, as highly individualized products are demanded in increasingly smaller quantities within shortened product life cycles in a more and more volatile production scenario with growing fluctuation in tasks and personnel – calling for new ways to build competencies and for lifelong learning to adapt to these ever new tasks [2, 3, 4]. The induction of such volatility in complex systems such as a production setting, urge these entities for a high degree of agility. With this in mind, learning factories provide an environment for agile learning and may thereby support a company’s long-term success in the future [5]. Besides the provision of modern learning environments for education and vocational training, learning factories also arise for applications in research and provide an ideal setting to collect production based real-time data. Particularly with attention to the Industrie 4.0 paradigm [6, 7] learning factories serve as an advantageous surrounding for testing new work processes, new machinery and production of prototypes because there is limited risk of failure or major cost pressure [8].

In their article “Learning factories for research, education, and training”, Abele et al. call for an interchange of ideas that constitutes the motivation for the following introduction to the Demonstration Factory in Aachen and four exemplary use cases. The Aachen Demonstration Factory will be classified in said learning factory morphology in order to delineate it and to ensure comparability to other learning factories worldwide [8].

2. State of Art Learning Factory Concepts

The idea of learning factories goes back to 1994, when the first learning factories were founded at Pennsylvania State University, the University of Washington and the University of Puerto Rico-Mayaguez [9, 10]. In the decades to follow, an increasing number of learning factories were established not only covering different fields and branches but also with widespread features and sizes [8, 11]. In current times learning factories are used in branches even outside universities or industry as for example in consultancy or in fields of medicine. Furthermore, the learning factories’ scope is widening from not only education and vocational training to applications in fields of research and general competency training [12]. Approaches arise that aim to overcome such domain-gaps by implementing demonstrators and information-technology-based feedback loops between academia and industry. [13] Yet, the arising variety calls for a distinct way to classify learning factories and for a precise definition. For that purpose, the Initiative on European Learning factories, founded in 2011, initiated a CIRP Collaborative Working Group on learning factories in 2014 to establish a joint understanding of learning factories and related terms used in that context. The latest classification and description models for learning factories was published by Abele et. al. in order to deliver a morphology that allows for a distinction between learning factories [8]. In detail, this morphology classifies and categorizes a learning factory in seven dimensions according to its features. The dimensions consist of the purpose and targets, the process, the setting, the product, didactics, the operation model and lastly the metrics of the respective learning factory.

Following the determinations by the CIRP Collaborative Working Group on learning factories, a learning factory finds its definition in a narrow and a broader sense. In a strictly definitional contemplation, the composition of the words learning and factory suggest an agglomeration of both terms, combining the two fields: A factory in the narrow sense signifies a real production system and implies the manufacturing of a physical product while the aspect of learning highlights the – potentially simulative – gain of knowledge as a purpose. It makes use of a real value chain, authentic processes on several work stations and organizational aspects of production. [8] In contrast to that, broader sense learning factories for example address services instead of a physical product. [8]

An example for a learning factory in the narrow sense is the Center for Industrial Productivity located in Darmstadt, run by the Institute of Production Management, Technology and Machine Tools of TU Darmstadt [8] as opposed to the McKinsey Capability Center in Munich which also offers Lean IT classes as an example for a learning factory in the broader sense [14]. The Aachen Demonstration Factory will be allocated later in this paper. Figure 9 displays the classification of these and several other learning factories.

Regardless of this distinction the factories’ main goals are either innovation in fields of technology and organization if used for research or an effective competency development if used in education and training. [8] Improving the learning factory and keeping it up to date is essential and requires a sustainable business model.
3. Hybrid Production Infrastructure in the Aachen Demonstration Factory

The fast developing progress of information and communication technology provide a wide range of new possibilities, complex production systems and processes that can be experienced in learning factories. Since 2013 the Demonstration Factory at RWTH Aachen allows for researchers and visitors alike, to investigate topics and problems in context of Industrie 4.0 as a part of the Smart Logistics Cluster [15] which is run in a consortium with partners from industry and university, like the Laboratory for Machine Tools and Production Engineering WZL. The Demonstration Factory with its size of 1,600m² is located within the RWTH Aachen Campus, where applied research and development combine logistics, production and services. Science along with academia aim to relate to actual trending industry research questions by employing modern and innovative solutions in collaboration effort. The goal within an Industrie 4.0 context is to distinguish the interlinking of practice, research, education and training. Therefore, the factory manufactures actual marketable products that are to be sold to consumers and business customers: an electric go-kart and an electric compact car. In their current state, the products are pilot products and prototypes in a small batch production, due for a larger scale production within the factory.

Thus, research and advancing education in a real production setting constitute the singularity of the hybrid Demonstration Factory. On the one hand, experiment based production research builds the basis for this hybrid production infrastructure, complemented by the spirit of applied science through long-term studies of manufacturing data and research validation in real production. Also, the further education that the Demonstration Factory aims to provide addresses aspects like a real production environment, practical use cases workshops, education in real production data or participatory education concepts for industrial learning.

Shaping the hybrid learning factory on the other hand, are the experimental production of small batches, learning and work with marketable products, that impose a changeable configuration of the production and the variation of production parameters. These influences are all properties of a real production system.

Visitors of the Demonstration Factory may partake in a variety of different guided and interactive tours. Participants engage in use cases and may experience the benefits hands on. While some courses and tours treat the production cycle of an electric small vehicle, this article focusses on four use cases along the value stream of a kart manufacturing process:

![Fig. 1. Four Use Cases along the Value Stream of a Genuine Manufacturing Process](image)

As outlined in Figure 1, required parts are commissioned with the support of a pick-by-voice system early in the value stream and supplied to the assembly area, while their location and status are constantly supervised by the indoor-positioning-system RTLS. In the later assembly process, the product is mounted with the support of three-dimensional assembly instructions. Overall production steering is supported by data collection and conditioning in a live shop-floor KPI visualization board.

The four cases are a selection of practical hybrid workshop cases that highlight the implementation, development and exploration of Industrie 4.0 applications and technologies and also support the kart manufacturing as they are all actual work processes. These use cases shall be detailed with further descriptions and examples in order to illustrate the hybrid production infrastructure:

**Use Case 1: Smartwatch-Extended Pick-by-Voice System**

This first use case addresses a real production challenge: As the Demonstration Factory’s production is forecast to become even more versatile, agile and volatile in the future, logistics workers face variant complexity and steady product variations; they need to adapt to ever changing order picking lists in the warehouse routine. In this use case, participants perform such a picking routine, first using a conventionally printed picking list to pick up the kart’s components. Afterwards and for the purpose of comparison, they use a smartwatch-extended pick-by-voice system to
collect parts identical to the ones used by the kart manufacturing personnel. The participants experience an increase in picking time with fewer errors due to the multi-sensual support. The digital equipment assists by guiding through the warehouse, visualizing the information, providing immediate feedback to ensure the correct selection and enabling natural interaction via voice by answering and confirming given orders or asking work-related questions. The systems are linked to the enterprise resource planning software in real time. Outside of this use case and in real production an anonymization of data would be required to avoid any possibility of worker surveillance.

**Use Case 2: Production Real-Time Locating Systems**

Experience in the Demonstration Factory research shows, that industrial process improvement may be generated by a real time movement visibility of assets, products and people on the shop-floor. Lacking transparency of the current processing status of individual and manual assembly orders has proven to be disadvantageous.

A cooperation consortium with industrial involvement, led by RWTH University institutes, enabled a real-time location tracking (RTLS) in the Demonstration Factory. These RTLS-tags are positioned on resources and allow for lateral and angular live positioning on the shop-floor up to a precision of 30cm. These tags, for example attached to a material provisioning dolly, are used during production, as well as for classes and courses, to follow the work flow – Thus enabling real time display of assembly progress and cycle times. The data feedback is recorded into ERP-systems and provides automated reports for production planning and control, for example on the deviation of planned orders.

Such position-based order tracking allows for easier and more transparent management of administrative, logistics, production and engineering processes in a lean sense. Precise time-stamps may be recorded once the beacon traverses predefined virtual areas: The periods and ratios of productive times and non-value-added time can be analyzed in terms of process planning potentials. The record of paths travelled allow detecting more agile or flow oriented factory layouts. Participants experiment with the beacons on the shop-floor and discuss conclusions. The system relies on battery technology and might be improved by beacons that signal their battery status once they run empty.

**Use Case 3: CAD-Based Three-Dimensional Assembly Instruction**

One use case provides three-dimensional assembly instruction based on CAD-drawings and it represents one of the final steps of the production process and exemplifies the implementation of support systems in the assembly line. Participants step in for manufacturing personnel and are put in charge of assembling the still uninstalled parts of the produced good. While they initially have to perform the assembly steps with a printed two-dimensional manual, they subsequently experience various enhancements using the three-dimensional instruction given on an installed touch screen, where further information on tools, materials provisioning and a description of next work steps is interactively displayed. The relevant three-dimensional instructions may be loaded directly from the engineering department’s data base by scanning a RFID tag which was attached to the respective kart in advance. This ensures an up to date data set in the sense of one single-source of truth. If they were to rerun the assembly steps, participants could use individualized and stripped-down instructions depending on their skill level and thereby save further non-value added time. In the end the participants have learned how improved and individualized instructions can boost the learning curve, prevents mix ups and provide a data foundation for better process time scheduling. [16] This case does not yet aim at increasing picking times, which could be further enhanced by installing a pick-by-light solution.

**Use Case 4: Production Management: Shop-Floor Visualization for KPIs and Team Meetings**

Shop-floor management on an electronic performance board, as used in both the kart and electric vehicle production of the Demonstration Factory, constitutes this fourth use case. The participants gather insight on how shop-floor management works via digital KPI boards from all production work steps. The visualization of the continuous improvement process aims to improve the quality of products, processes and services. Being introduced to various cascades and patterns of shop-floor meetings, the participants discuss problems and propose solutions to reduce weaknesses. Eventually, the participants further their knowledge in production management, especially how loss of value added time may be reduced by automatically updated computer-analyzed KPI values that facilitate controlling improvement and increase transparency, and fast root-cause-analyses. By an interdisciplinary exchange independent
problem solving improves on the basis of the visualizations in close proximity to the actual work place with frequent updates of the latest results. In comparison to manually aggregated shop floor boards, a digital version runs the risk of personnel losing grasp of the data acquisition and its compilation. Partially manual, yet IT-supported, data input, e.g. via tablets, might mitigate that risk.

4. Hybrid Production in the Context of Learning Factory Morphology

Along the scientific debate on learning factories the morphology to classify learning factories, that Abele et. al. [8] present, may be considered the most current consensus. The Aachen-based approach of a hybrid production infrastructure within their Demonstration Factory, exemplified by the previously introduced use cases, shall be classified within this morphology and its seven dimensions.

4.1 Operation Model

The Demonstration Factory is based on the RWTH Aachen Campus and it’s developed and run by the university’s academic institutions. As the learning factory is available for internal training just as for external visitors, the business model is open with resources available to external companies, student classes and internal research projects. The courses are primarily taught by researchers and consultants that demonstrate the cases. The sustainability of the operation is ensured by internal funds supported by the research funds, sales of the produced products and course fees.

4.2 Purpose and Targets

The main purposes of the Aachen learning factory are research training for heterogeneous groups of middle management, semi-skilled workers and students, and industrial production. Actual industrial production has not yet been considered in the morphology but this addition would open it up for further learning factories that are attached closer to manufacturing companies or to hybrid learning factories similar to the one in Aachen. Here, new aspects, cases and experiments within the theme of Industrie 4.0 are conducted in the setting of real production processes. Additionally, the learning factory may be used as a test environment or for advertisement of production. The targeted industries mainly include mechanical and plant engineering, logistics and automotive industry while the subject related learning contents are focused on production management, organization and cyber physical production systems, lean management, works system design and human machine interface, as all exemplarily addressed in the above mentioned shop-floor visualization and the 3D assembly use case.

The Aachen Demonstration Factory is not only a research object, it also represents a research enabler, as the actual volatile and ever-changing production setting for example constantly poses new research questions.

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**Fig. 2. Operation Model of the Aachen Demonstration Factory**

**Fig. 3. Purpose and Targets of the Aachen Demonstration Factory**
4.3 Process

A real production – even in a learning factory – shall incorporate significant holistic parts of the product, factory and order life cycle. As manufacturing, assembly and logistics interconnect these cycles, they need to be in special focus of the factory. The use cases presented above underline the significance of these processes, the pick-by-voice system supports logistics, the three-dimensional-instruction case is located in assembly, RTLS interconnects all manufacturing steps and the shop-floor visualization spreads throughout the whole product life cycle. In a discrete small series production based on actual market orders, goods are produced in a flow production or in alternative workshop manufacturing. Physical processes like cutting, forming or joining are partly automated and base for the use cases presented above. Human interaction with computer based systems like the three-dimensional assembly or the real time location system showcase a hybrid degree of automation. This level of automation enables a hybrid production in terms of a genuine flow production through trained personnel to satisfy market demands and a simultaneous workshop manufacturing through untrained workshop participants.

![Fig. 4. Processes in the Aachen Demonstration Factory](image)

4.4 Setting

The physical learning factory in Aachen is supported by an entirely digital infrastructure. The work system levels of the life-size factory include real work places, systems, the factory and a network. Besides that, mobility, modularity and a scalability characterize its changeability, to the extent that all dimensions, layout, product features, the product design itself, used technology and product quantities can be adapted. IT systems with the integration of three different ERP systems and corresponding support software, cover all steps of the production. The mentioned three-dimensional assembly instruction use case makes use of engineering and production IT-systems alike. Furthermore, several ERP interfaces allow for direct integration of data by the RTLS tag, as also represented in an above case.

![Fig. 5. Setting of the Aachen Demonstration Factory](image)

4.5 Product

The two products, an electric compact car and an electric kart are mostly self-developed and fully functional. While the electric car is currently prepared for a larger scale production, the cart is already available on the market and sold in two to four variants. For the current model, about up to 100 components are required. Regarding the capacities, the number of different products of the Demonstration Factory could be scaled up to four in similar complexity.

![Fig. 6. Products of the Aachen Demonstration Factory](image)
4.6 Didactics

The Demonstration Factory’s educational goal aims at technical and methodological competences. Also, activity and implementation oriented competencies are taught to improve cognitive as well as psycho-motoric skills. Didactics are founded on training use cases with an emphasis on demonstration, yet they primarily focus on actual do-it-yourself experience. This specialty focus has not yet been represented in the morphology by Abele et. al. and may be a valuable addition in order to open up to the classification of more production and real-life-based learning factories. The trainings in the Demonstration Factory are available both standardized or customized. Researchers or consultants instruct learning games in form of practical lab courses. Both, practical parts and theoretical foundation are provided and may optionally be evaluated. To ensure steady improvements, a feedback of participants is part of every course.

<table>
<thead>
<tr>
<th>dimensions learn. targets</th>
<th>technical and methodological competencies</th>
<th>social &amp; communication competencies</th>
<th>personal competencies</th>
<th>activity and implementation oriented competencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>competence classes</td>
<td>greenfield (development of factory environment)</td>
<td>brownfield (improvement of existing factory environment)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>learn. Scenario strategy</td>
<td>onsite learning (in the factory environment)</td>
<td>remote connection (to the factory environment)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>communication channel</td>
<td>instructor</td>
<td>demonstration</td>
<td>closed scenario</td>
<td>open scenario</td>
</tr>
<tr>
<td>role of the trainer</td>
<td>presenter</td>
<td>moderator</td>
<td>coach</td>
<td>instructor</td>
</tr>
<tr>
<td>type of learn. environment</td>
<td>tutorial</td>
<td>practical lab course</td>
<td>seminar</td>
<td>workshop</td>
</tr>
<tr>
<td>standardization of trainings</td>
<td>standardized trainings</td>
<td>customized trainings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>type of training</td>
<td>prerequisite</td>
<td>in advance (en bloc)</td>
<td>alternating w/ pract. parts</td>
<td>based on demand</td>
</tr>
<tr>
<td>learning success evaluation</td>
<td>feedback of participants</td>
<td>learning of participants</td>
<td>transfer to the real factory</td>
<td>econ. impact of trainings</td>
</tr>
</tbody>
</table>

Fig. 7. Didactics of the Aachen Demonstration Factory

4.7 Learning Factory Metrics

With a total area of 1600m² the Demonstration Factory offers about ten different standardized trainings. Depending on the training the number of participants ranges between ten and thirty and last between one to five days. The factory welcomes up to 8000 participants each year with a total capacity utilization reaching close to 100%. The factory employs five to nine full time equivalent workers, mostly student assistants. As the given morphology only considers learning factories up to 1000m², options of 1000-2000 m² and 2000m² and above shall be implemented.

<table>
<thead>
<tr>
<th>no. of participants per training</th>
<th>&lt; 5 participants</th>
<th>5-10 participants</th>
<th>10-15 participants</th>
<th>15-20 participants</th>
<th>&gt; 30 participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>no. of standardized trainings</td>
<td>1 training</td>
<td>2-10 trainings</td>
<td>&gt; 20 trainings</td>
<td>&gt; 50 trainings</td>
<td></td>
</tr>
<tr>
<td>average duration of single training</td>
<td>&lt; 1 day</td>
<td>1-2 days</td>
<td>3-5 days</td>
<td>5-10 days</td>
<td>10-20 days</td>
</tr>
<tr>
<td>participants per year</td>
<td>&lt; 50 participants</td>
<td>50-200 participants</td>
<td>201-500 participants</td>
<td>501-1000 participants</td>
<td>&gt; 1000 participants</td>
</tr>
<tr>
<td>capacity utilization</td>
<td>&lt; 1%</td>
<td>1-10%</td>
<td>10-20%</td>
<td>21-50%</td>
<td>51-75%</td>
</tr>
<tr>
<td>size of LF</td>
<td>&lt; 100 sqm</td>
<td>100-300 sqm</td>
<td>300-500 sqm</td>
<td>500-1000 sqm</td>
<td>&gt; 1000 sqm</td>
</tr>
<tr>
<td>no. of trainings</td>
<td>&lt; 200 trainings</td>
<td>&gt; 200 trainings</td>
<td>&gt; 500 trainings</td>
<td>&gt; 1000 trainings</td>
<td></td>
</tr>
<tr>
<td>FTE in LF</td>
<td>&lt; 1 FTE</td>
<td>2-6 FTE</td>
<td>8-12 FTE</td>
<td>14-20 FTE</td>
<td>&gt; 20 FTE</td>
</tr>
</tbody>
</table>

Fig. 8. Metrics of the Aachen Demonstration Factory

Contemplating on the morphology by Abele et. al. and the classification in this chapter, the Aachen Demonstration Factory may be regarded as a learning factory in the narrow sense with the yet unusual feature of its hybrid production infrastructure. Its special property, the mix of training and research, combined with the dual operating system of academia and industrial production, are classified in the following grid in comparison to other learning factories.

5. Conclusion and Outlook

Learning Factories offer potentials for academia as well as for industrial applications. While they provide resources for practical education in the fields of production engineering, they also provide capacities for courses, labs, seminars and workshops in the factory with the goal of providing education to external visitors just the same. Learning factories may also play a key role in the practical the training of personnel and a company’s workforce. This article introduced the Aachen Demonstration Factory, that plays out its competencies in the interlinkage of these opposites in its hybrid production setting. By explaining exemplary educational use cases along the value chain of a genuine production and by highlighting the hybrid production system the uniqueness of this particular learning factory was elaborated. As the classification of the Aachen Demonstration Factory was mostly successful within the seven segments of the morphology presented by Abele et al., only minor changes would enhance the morphology even further. These additions were presented in their respective chapters and include an option to integrate production as a
main purpose of the factory and also to aim a learning factory’s learning scenario strategy to a do-it-yourself experience and thereby allow for a more intuitive classification of hybrid or industrial learning factory scenarios.

The combination of research and real production is most advantageous also for producing companies [5], as potentials of further systematic development arise by learning in a real system: Improvements and innovations can be generated in a learning environment and quickly be linked and transferred to productive manufacturing processes.

Fig. 9. The Aachen Demonstration Factory in the Learning Factory Typology in Reference to Abele et al. [8]

References