Analysis of Digitization and Automation in Manufacturing and Logistics Utilizing an Enhanced Smart Factory Assessment

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***Abstract*—An effective improvement of production and logistics systems directing towards the so called Smart Factory initially requires a structured capturing approach which comprises an evaluation of the current state regarding Lean and Digital Manufacturing excellence. Such an integral consideration of systems makes target conflicts transparent and allows deriving optimal decisions towards the future of production and logistics. Against this background the Smart Factory Assessment (SFA) was developed, applied and validated already at more than a dozen of manufacturing sites around the globe. This paper shows and discusses methodology, practical application and findings regarding its enhancement. A special focus is set here on the assessment of digitization and automation maturity in manufacturing and logistics through process landscaping. The developed expert assessment consisting of twelve categories enables the definition of concrete transformation paths directing to Lean and Digital Manufacturing excellences, paving the way towards Smart Manufacturing.**

***Index Terms*—automation, digitization, holistic production system, industry 4.0, integration, lean production, smart manufacturing.**

I. Introduction

Over the past few years, the idea of Digital Manufacturing or Industry 4.0 has increasingly manifested itself in science as well as in industrial practice. It depicts the trend towards digitization, automation and the increasing use of Information and Communication Technology (ICT) in the manufacturing environment [1]. In this context, the concept of Digital Manufacturing comprises a large number of technologies to enable the development of a digital, automated or even autonomous manufacturing environment, as well as the digitization of the whole value chain [2], [3].

In future factories and supply chains, systems being capable of Digital Manufacturing will utilize network-based software services to steadily improve performance and to increase agility [4]. In this context, the most important trends and characteristics of an Industry 4.0 implementation are being defined for further consideration [1], [5]–[9]:

- End-to-end digitization of every production and logistics related flow of information.
- Integration of all participants of value creating networks like people, machines, products, external companies, and logistics. It is distinguished between two types of integration:
  - Horizontal integration of stakeholders between companies including customers and suppliers.
  - Vertical integration of internal stakeholders on the shop floor and to the enterprise planning level.
- Automation of production and logistics processes up to fully autonomous systems.
- Automation of information flows and information processing to cope with increasing amounts of data.
- Local or decentralized decision making and associated real time ability of sensor systems.

The realization of these characteristics of Digital Manufacturing raises the expectation of an improved process quality, reduced lead times and performance and productivity advantages. These goals of Digital Manufacturing also apply for the proven methods and approaches of Lean Manufacturing: They significantly contribute to success and performance not only of manufacturing companies. Lean Manufacturing methods strengthen competitiveness by eliminating waste throughout the supply chain [10]. This leads, among other things, to significant improvements regarding lead times. The joint application of Lean and Digital Manufacturing levers will in the context of this article be referred to as Smart Manufacturing [11], [12].

Implementing the vision of a Smart Factory as benchmarking environment for a holistic integration of Lean and Digital Manufacturing is challenging. Currently, many production facilities show strong interest in intelligent solutions and the advantages associated therewith. Nevertheless, transferring concrete implementation strategies at an excellent cost-benefit ratio to existing heterogeneous manufacturing and logistics environments still poses a major challenge [13], since the starting point for transformation into more advanced systems is largely unknown. The depicted maturity assessment enhances transparency regarding the current state, assesses and poses concrete improvement

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potential in seven Lean and five Digital Manufacturing categories. In the course of this assessment, digitization and automation maturity are measured based on the core processes within the systems in focus. The use of process landscaping is proposed in this paper.

In the context of this article, the term "maturity" refers to a "state of completeness, perfection or readiness" [14] and implies certain progress concerning the development of a system. Accordingly maturing systems develop their abilities in the course of time with regard to the achievement of a certain desired future state.

II. The Smart Factory Framework

The Smart Factory Assessment can form the starting point for extensive transformation projects and provide a basis for structured improvement activities utilizing further methods. It is conceptually embedded in the Smart Factory Framework, see Fig. 1. The assessment (1), whose extension is in focus of this paper, enables an initial maturity evaluation at factory / divisional level and shows first areas of activity [12].

In the next step (2), focal value streams in this division or plant are being analyzed via Smart Value Stream Mapping (SVSM). This is being executed extending the value stream method by the criteria digitization, automation (process and information) and vertical and horizontal integration. SVSM enables comprehensive and fact-based decision-making, in particular for possible optional actions which are being derived from both focuses (Lean and Digital Manufacturing) [11].

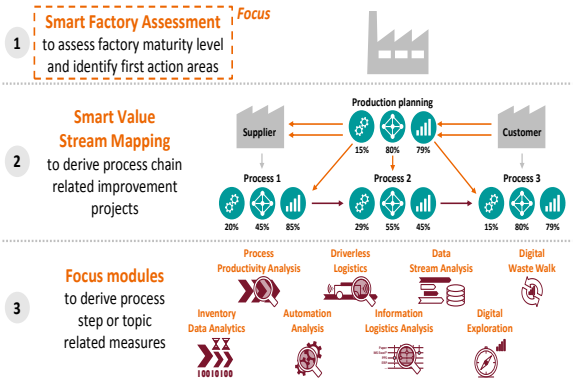

Figure 1. The smart factory assessment as first part of a structured transformation framework (Smart Factory Framework).

Depending on the desired focus (3) e. g. an Information Logistics Analysis designed for capturing information flows and storage media in manufacturing [15], a detailed process assessment with the aid of time recording via a Process Productivity Analysis, an Automation Analysis or analyses of administrative support processes are feasible. Further concepts and methods are steadily integrated into the framework [12].

III. The Enhanced Smart Factory Assessment

A. Conception

The Smart Factory Assessment conceptually is based on a variety of preliminary work and assessments being part of the paradigm classes of Lean and Digital Manufacturing. As an example, the Rapid Plant Assessment of the University of Michigan, the Siemens Production System Screening, the VDMA Guideline Industry 4.0 [16], the Digital Manufacturing Readiness Check [17], Industry 4.0: How to navigate digitization of the manufacturing sector [18] and the Digital Manufacturing maturity model [19] can be mentioned, from which several elements are being used. The process model for developing maturity models after [20] came to use when developing the assessment.

The assessment itself thematically consists of twelve categories, whereof seven can be assigned to a Lean focus and five to a Digital Manufacturing focus. Among the categories there is one to assess a characteristic product (Smart Products) which is manufactured in the plant to be examined, see Fig. 2.

Figure 2. The seven lean (dark) and five digital manufacturing (light) categories of the smart factory assessment.

B. Procedure and Practical Application

Approach. The following section describes the procedure of the assessment which has already been proven in more than a dozen international improvement projects. The assessment is usually conducted at manufacturing plants or logistics hubs, where physical material processing or transportation takes place. There are four predefined phases which need to be passed through, see Fig. 3.

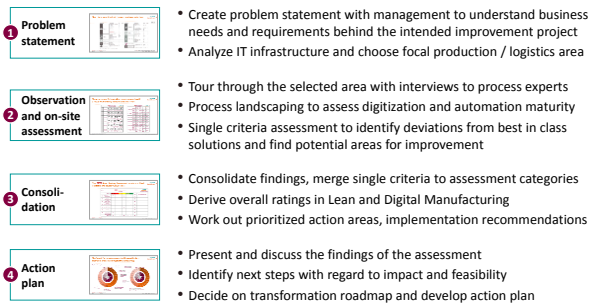

Figure 3. Procedure behind the expert-based smart factory assessment.

The first three of the phases can, depending on the scope, be performed by ideally two assessment experts within one day. This characterizes one of the

assessment's unique selling points, it is meant to be a quick evaluation.

Problem statement. Starting point of the assessment is a structured, approximately one-hour interview with the management addressing the strategic orientation, the biggest challenges, the investments both carried out and planned, the IT infrastructure, the employee competencies, the product portfolio, expense allocation and the most significant improvement levers of the site. Outcome is a common problem statement for the intended improvement project. At this point in time also key performance indicators for the project are defined [21].

The aim is to collect data on the current situation on-site and regarding the priorities of the division to subsequently being able to express targeted recommendations.

Observation and on-site assessment. In the course of a tour through the physical production or logistics areas with the divisional representatives, process owners, representatives of Industrial Engineering and IT, the Lean sub criteria are initially being discussed and questionnaire-based captured. Here the aim is to cover a preferably wide range of on-site characteristics to receive a holistic picture of the situation.

Furthermore, a joint evaluation of the Digital Manufacturing sub criteria is carried out directly on the shop floor and the results captured in a structured way. Each pictured criterion receives a certain maturity rating on a 4-or 5-point Likert scale, see Fig. 4.

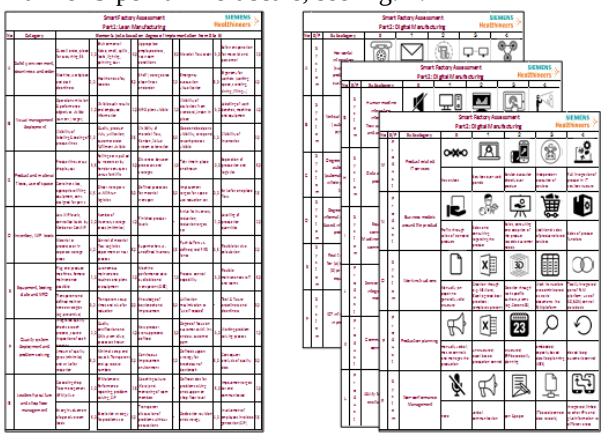

Figure 4. Documents used during the expert-based smart factory assessment.

Two aspects of the above introduced characteristics of Digital Manufacturing or Industry 4.0 are the two categories digitization and automation. In the course of the Smart Factory Assessment, digitization and automation are both assessed on a process base. In a first step all core and support processes of the organizational unit to be assessed need to be identified and mapped in a structured way following certain standards. Therefore the creation of a so called process landscape has proven to be suitable. Process landscaping is useful to enable a future analysis of the interlinked processes within an organizational unit [22], [23]. A process landscape shows what processes are alive in a certain area and how they are interconnected.

After the process landscape has been derived and visualized with the use of expert interviews and e. g. quality management documentation, the evaluation of digitization and automation can be performed.

The digitization rate of a process is defined as the quotient of the number of input and output artifacts in a process that are processible via IT systems and the sum of all input and output artifacts of a process.

Furthermore the automation rate of a process landscape consists of two basic components: (1) the automation rate of physical manufacturing or logistics activities and (2) the automation rate of information processing. Both are calculated by dividing the automated process times (without human process participation) by the overall process time. Fig. 5 shows the outcome of this activity.

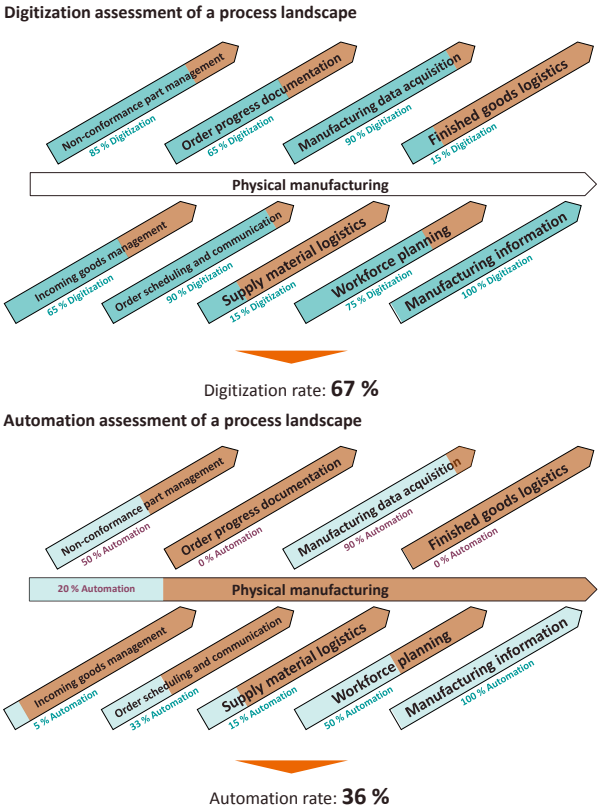

Figure 5. Illustrative assessed landscapes of manufacturing / logistics core and support processes regarding digitization and automation.

Consolidation. Based on the sub criteria ratings behind the seven Lean and five Digital Manufacturing categories and the information gained on-site, action recommendations can be derived after a consolidation of results. This phase is used to consolidate the expert sub criteria ratings into maturity levels for each of the twelve categories. The expert assessments of the sub criteria are being reflected collectively before an overall decision concerning the scoring of each criterion is reached. This is done in a team approach to reach consensus and buy-in. The initial qualitative statements out of the short interview are being quantified with the aid of an assessment scheme on a Likert base and fed into the overall assessment of the individual categories.

At this stage, also the reflection of best practices and improvement potentials in the individual categories takes

place, always considering the background of the initially specified optimization goals (problem statement). Finally, a summary of the results is being generated and possible target values for the individual categories are being defined in collaboration with the divisional representatives, see Fig. 6.

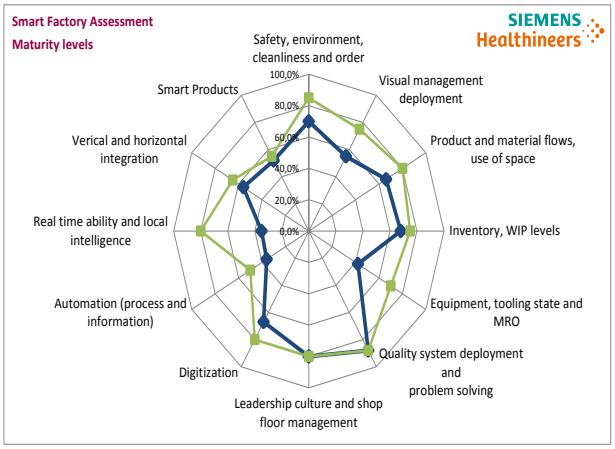

Figure 6. Illustrative result presentation of the smart factory assessment including current (dark) and aspired (light) maturity.

Action plan. To follow up on the objective which was determined in the preceding expert interview, action items and implementation projects are scoped. This is done by a comparison of the current and aspired maturity and the definition of projects closing the resulting gaps. A standardized action plan is created.

Actions can be derived out of two data sources: (1) Individual actions that come up during the on-site assessment and (2) standardized levers that can be tailored to the site's needs. Fig. 7 shows in an illustrative manner a series of standardized optimization levers for further project planning.

They are based on a variety of proven Lean and Digitization methods and not exhaustive. Based on structured interviews as well as analyses of the assessment results they are being preselected and present additional recommendations for action.

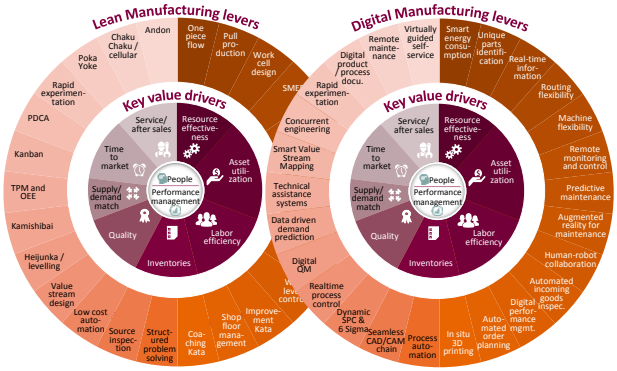

Figure 7. Predefined improvement levers as part of the action recommendation after the execution of the smart factory assessment.

IV. Conclusions

The paper shows an enhanced procedure to systematically map the maturity of a manufacturing site or logistics hub regarding Lean and Digital Manufacturing. Digital Manufacturing or Industry 4.0 maturity is measured in the categories digitization, automation (process and information), real time ability and local intelligence, vertical and horizontal integration as well as smart products. The evaluation approach for digitization and automation follows process landscaping, where core and support processes on-site are identified and assessed regarding their respective maturity. So far the previously executed assessments show certain characteristics in an industrial environment:

- The assessment serves as a starting point for holistic optimization projects, e. g. by applying further analysis and conception methods of the above-mentioned Smart Factory Framework, since it supports a structured yet also creative discussion of optimization levers.
- It enables the derivation of targeted, concrete and immediately applicable measures leading to an action plan.
- It creates a common understanding between management and operational level on the necessity of an integrated optimization and reinforces team awareness concerning the site's status quo.
- Simultaneously, it assists in dismantling fears of contact especially concerning Digital Manufacturing, since it operationalizes this term to actions.

It is feasible to conduct the assessment within one day. The assessment enables an integral examination of two lever groups to enlarge the solution space for improvements, to define the following steps in a structured manner and to derive an action plan.

The Smart Factory Assessment presents the first phase of the also introduced Smart Factory Framework, a methodical framework for integral, structured and implementation-oriented improvements regarding Lean and Digital Manufacturing.

References

[1] T. D. Oesterreich and F. Teuteberg, "Understanding the implications of digitisation and automation in the context of Industry 4.0," *Computers in Industry*, vol. 83, pp. 121-139. 2016.

[2] H. Lasi, P. Fettke, H. G. Kemper, T. Feld, and M. Hoffmann, *Industry 4.0. Business and Information Systems Engineering*, vol. 6, no. 4, pp. 239-242, 2014.

[3] R. Schmidt, M. Moehring, R. C. Haerting, C. Reichstein, P. Neumaier, and P. Jozinovic, "Industry 4.0 potentials for creating smart products," in *Proc. 18th Conf. on Business Info Systems*, Poznan, 2015.

[4] B. Kulvatunyou, N. Ivezic, K. C. Morris, and S. Frchette, "Drilling down on smart manufacturing – Enabling composable apps," *Manufacturing Letters*, vol. 10, pp. 14-17, 2016.

[5] H. Kagermann, W. Wahlster, and J. Helbig, "Implementation suggestions for the future project industry 4.0," *Frankfurt am Main: Acatech*, 2013.

[6] S. Choi, K. Jung, B. Kulvatunyou, and K. C. Morris, "An analysis of technologies and standards for designing smart manufacturing systems," *Journal of Research of the National Institute of Standards and Technology*, vol. 121, pp. 422-433. 2016.

[7] S. Jacobson, "Business value of MES," *MESA International*, 2013.

[8] M. Hermann, T. Pentek, and B. Otto, "Design Principles for Industrie 4.0 Scenarios," in *Proc. 49th Hawaii International Conference on System Sciences*, 2016, pp. 3928-3937.

[9] R. Obermaier, *Industrie 4.0 as Entrepreneural Design Task (in German)*, Wiesbaden: Gabler-Verlag, 2016.
[10] M. Holweg, "The genealogy of lean production," *Journal of Operations Management*, vol. 25, pp. 420-437, 2007.
[11] M. Haschemi and M. P. Roessler, "Smart value stream mapping: an integral approach towards a smart factory," in *Proc. 3rd International Congress on Technology - Engineering & Science*, 2017.
[12] M. P. Roessler and M. Haschemi, "Smart factory assessment (SFA): A method for integral maturity assessment of production and logistic regarding lean and industry 4.0 (in German)," *ZWF*, vol. 112, no. 10, pp. 699-703, 2017.
[13] U. Dombrowski, T. Richter, and D. Ebentreich, "On the way to the fourth industrial revolution (in German)," *Fuehrung + Organisation*, vol. 84, no. 3, pp. 157-163, 2015.
[14] J. A. Simpson and E. S. Weiner, *The Oxford English Dictionary*, Oxford: University Press, 1989.
[15] T. Meudt, M. P. Roessler, J. Boellhoff, and J. Metternich, "Value stream analysis 4.0: Holistic look on value stream and information logistics in production (in German)," *ZWF*, vol. 111, no. 6, pp. 319-323, 2016.
[16] B. Stahl, *VDMA Guideline Industry 4.0*, Frankfurt: VDMA-Verlag, 2015.
[17] K. Lichtblau and V. Stich, *Industry 4.0 Readiness (in German)*, Aachen: Impuls-Stiftung des VDMA, 2015.
[18] M. Digital, *Industry 4.0: How to Navigate Digitization of the Manufacturing Sector*, Munich: McKinsey & Company, 2015.
[19] H. Jodlbauer and M. Schagerl, *Maturity Model Industry 4.0 – A Procedure Model for the Identification of 4.0 Potentials (in German)*, Bonn: Society of Informatics, 2016.
[20] R. Knackstedt, J. Poeppelbuss, and J. Becker, "Process-model for development of maturity models (in German)," *Wirtschaftsinformatik Proceedings*, pp. 534-544, 2009.
[21] G. W. Evans and S. M. Alexander, "Using multi-criteria modeling and simulation to achieve lean goals," in *Proc. Winter Simulation Conference*, Washington, December 9-12, 2007, pp. 1615–1623.
[22] V. Gruhn and U. Wellen, "Structuring complex software processes by process landscaping," in *Software Process Technology*, R. Conradi, Ed., Berlin: Springer, 2000.
[23] O. Skarlat, "Elastic manufacturing process landscapes conference," in *Proc. 8th ZEUS Workshop*, Austria 1562, 2016.

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