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Reflections from a hybrid approach used to develop a specification of a shopfloor platform for Smart Manufacturing in an engineered-to-order SME

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Abstract. This paper describes the steps that an engineered-to-order SME firm took to identify their requirements for a shopfloor Manufacturing Execution System (MES). The firm had limited experience and followed a hybrid Design Thinking / Lean approach to develop and test use cases that could be reviewed with stakeholders in the factory to confirm their value in supporting the critical economical outcomes of single piece flow in the factory. The firm created a set of requirements based on use cases and a roadmap for the further development of the MES. During the investigation, the foundation work necessary to develop a shopfloor platform was supported by a digital maturity assessment tool. The higher-level analytical micro-services were dependent on easily accessible transactional data from the system. The work's limitations are that implementation is not part of this study and that the approach taken must be compared with more traditional approaches.

Keywords: Smart Manufacturing, Design Thinking, Lean, Manufacturing Execution Systems, SME.

1 Introduction

Shopfloor materials and work planning can now be automated using Manufacturing Execution Systems (MES) that allow firms to track and document raw materials' transformation to finished goods [1]. Today it is possible to integrate MES with other digital technologies to move to predictive planning environments [2]. This enables the MES to provide information to help decision-makers to optimize and improve production output [3]. A gap remains, with many firms continuing to use Excel-based planning processes without the integration of more advanced digital tools [4].

This paper's motivation comes from the desire to understand how an SME in an engineered-to-order (ETO) environment can design and specify a shopfloor platform that provides advanced monitoring, diagnostics, and prediction to be integrated into the business. Planning on both an operational and strategic basis requires the controlling MES to be connected to systems that support production optimization. An ETO environment requires agile planning and replanning to adapt to the dynamic production environment; for example, workers may be absent, machines may require maintenance, or the sales team may request variations to orders. This occurs in a complex environment with multiple perspectives, where adaptations to the production plan need to be integrated into the day-to-day operations.

This study follows a firm in an ETO environment using a hybrid approach based on Design Thinking and a traditional Lean approach to develop a concept to future-proof their MES implementation. The research question for this study is: "*how can an SME with limited experience successfully specify the requirements for a smart manufacturing shopfloor platform that integrates with an MES, supporting the operation and strategic optimization?*"

2 Literature Review

Production needs to evolve to continuously meet customer expectations [5], and to fulfill individual customer requirements, integrated business solutions are needed. The flexibility and service orientation required can be achieved through digital manufacturing [6]. Under the term "Industry 4.0" the German government initiated a strategy in 2011 to address such changes [7]. A holistic approach in terms of driving the transformation into tomorrow's production paradigms is necessary [8]. This review will consider Smart Manufacturing and how it has been integrated into manufacturing businesses.

Through the application of Industry 4.0 technologies, a high level of process integration in human-machine collaboration can be achieved with respect to shopfloor equipment [9]. To attain flexibility and adaptability within the digitization of manufacturing, not just technological, but also organizational and cultural aspects are relevant [10], [11]. Schuh et al., [10] proposed an Industry 4.0 maturity index which leads to a roadmap encompassing tailored actions within these aspects. According to the maturity index, computerization and connectivity must first be created in the context of digitization, so that smart factory initiatives can progress. In other words, to achieve the objective of smart factories, the collecting and processing of data gathered within the value stream is crucial [12]. Techniques such as simulation, data analytics, and optimization will help to build a better understanding of manufacturing processes, as well as creating transparency throughout the value stream on the shopfloor [9]. This is possible today for single production lines, but the major challenge is accomplishing this along the value stream [13].

Many companies have monolithic IT-structures, based on Enterprise Resource Planning (ERP) systems which can make shopfloor digitization difficult [8]. According to Fend & Hofmann [14] platform models are standards, which provide a basis for the further development of application programs. For the production floor, a tool that can assist such a paradigm shift in operation technologies is the MES [15]. Many systems are built based on standards as ISA 95, VDI 5600, MESA or similar [1], within those are functions for resource management, quality management, and manufacturing control, and often customer requirements are defined based on these standards [1]. Today, MES are mainly task oriented and lack the forward-looking tools for analytics and prediction [1], [10], [16], but as we move towards smart manufacturing, information systems within the cyber world will have new requirements to use shopfloor data to achieve more flexible production [13]. Besides more advanced analytical functions, future requirements can be summarized in horizonal and vertical integration, decentralization, and connectivity [15]. Althoughthe adoption of MESs in companies is increasing [17], currently an approach is missing to define requirements for driving data-enabled decisions within the smart factory environment to realize its potential benefits [13]. However, the focus should not solely rely on technological aspects but should be arranged in a holistic approach focusing also on organizational structures and business process reengineering [17]. Especially in manufacturing companies, Lean tools are seen as a foundation to start with, prior to the commencement of digitization activities [11], [18].

3 Methodology

A single case with structured analysis and reflection provides the foundation from which we may start to generalize a solution [19], [20]. In this instance, the subject is the development of a concept for the system within the firm, which was defined by the research question. The purpose is exploratory, to test the theoretical approach of Design Thinking (Fig. 1) using a retrospective case in which one of the authors was embedded [21]. The Design Thinking approach was enhanced by Lean tools, as Lean is a relevant foundation to increase manufacturing performance and therefore build the basis for a highly integrated system [11]. Each of the major steps was stated, and the purpose of each documented, the tasks undertaken were described, and an analysis of the outcome with reflections/reviews was offered at the end of each task. Detailed interview data, use case and workshop output were all documented and archived as part of the case study investigation. A timeline of the study was constructed and represented the anchor for the subsequent results describing the period of data collection. Data collected was confirmed with the participants following the initial analysis and interpretation.

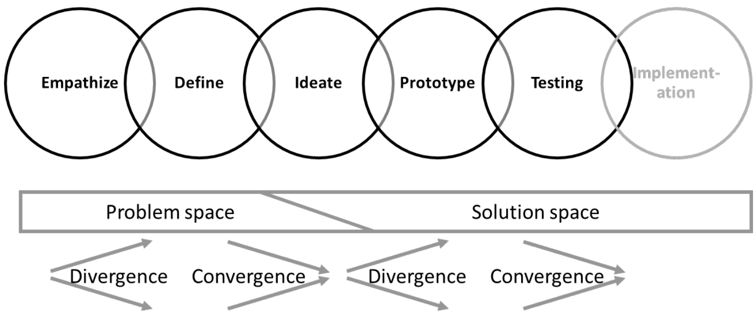


Fig. 1. Design Thinking approach based on Fleischmann et al., [22]

4 Results

Project work was undertaken during the period October 2020 to April 2021, and the findings are presented based on Design Thinking based methodology, with Lean tools added to support new perspectives. The results focus on the first five phases, as the aim of the work was to create an implementation plan or roadmap.

4.1 Case description

The company investigated operates within the furniture industry in Switzerland. Product and service quality at a competitive price-performance ratio are essential for customers. Therefore, the company does not release production orders until the products have been configured and ordered by the customer. Hence, the company does not produce into a distribution center as products are manufactured in a single piece flow, sequenced to the customer's delivery requirements. A consistent data flow starting in sales and going into production helps the company to ensure economic efficiency, while maintaining flexibility of products. Some individual Lean tools are used within the company however, a holistic implementation of Lean does not exist. The Design Thinking process is not yet established within the company.

4.2 Empathize

The purpose of this step was to generate a common understanding of stakeholder problems and to investigate the needs within the company. Table 1 presents the three major tasks and the insights generated.

Table 1. Empathize phase – approach, insights, and reflections

Task	Purpose	Insights and reflections
Literature research	Insights in state-of-the-art research, concepts and methodologies	- Paradigm change in manufacturing based on digitally-enabled manufacturing versus task/transactional orientation of MES. - Important to focus on flexibility and efficiency while complexity increases.
Value stream map	Understand the production process and philosophy	- Provided an overview of the processes, material flows and information flows within the factory. - The basis for further investigation and stakeholder identification.
Gemba walks (≥1/week)	Understand the actual job of the workforce today	- Excessive use of paper forms and Excel sheets. - Lack of accessibility to information. - Wide range of technologies in use.
Interviews (7)	Identify the pain points with current manufacturing philosophy	- Some data on orders is available, but poorly used for KPIs as well for analytics and prediction. - Problems need to be solved in a holistic approach using data for decisions.

The literature review described the necessity of digital tools in manufacturing to stay competitive. Such tools already exist within the firm but are not used to their full potential. The value stream mapping provided an overview of production processes as well as material and information flows within the factory. Gemba walks confirmed that the company has a wide range of technologies and automation in use. Data for the main processes are generated automatically and are provided directly to machines. Nevertheless, paper systems are primarily used to provide employees with information for production tasks. The interviews provided additional depth to the information obtained from the Gemba walks. The interviewees provided insights into the current problems in the production and supply chain. This was consolidated using a cause-effect diagram to provide a holistic view of the current situation, clearly showing that data was not being used for decision-making, as obtaining the relevant data was a fundamental problem.

4.3 Define

After divergence in the first phase, convergence of the pain points was needed. Therefore, information was consolidated in a cause-effect diagram built on the eight-dimensions: machine, material, method, manpower/mind power, management, measurement, milieu, and money (8Ms), which focus on relevant aspects of a production environment [17]. Table 2 highlights the major tasks performed within this phase.

Consolidating the information collected, the 162 pain points identified were aggregated into 55. Clustering using the 8Ms increased acceptance by stakeholders and also provided a useful overview. The summary of the pain points using a cause-effect diagram identified the need for improvements in all eight areas, but especially with operational dashboards and production planning. The root causes of these pain points showed that most of the workforce are aware of the problems and their possible causes. Having them clearly documented was supported by the stakeholders.

Table 2. Define Phase – Approach, Insights, and Reflection

Task	Purpose	Insights and reflections
Consolidation of pain points	Aggregation and summarization of pain points across multiple actors.	- Grouping in 8Ms provides different perspectives on the pain points. - Correct use of information leads to faster decisions with less effort.
Root-causes analysis	Deepen/broaden understanding of pain points and their causes.	- Take time on reflection and ask why performing this task is necessary. - Analysis and documentation were supported by stakeholders and delivered new insights to them.

4.4 Ideate

Awareness of the current problems allows abstract solutions to be generated to address them [23]. As described in Table 3, the ideas developed were examined to determine whether they could also use digital means to create a positive effect for production.

Discussing pain points with practitioners not only reduces misunderstandings, but often delivers practical ideas that might be included in abstract solutions. These show that a reactively managed production could be transformed into a more actively managed production, which might allow more flexibility. The rating of the solution approaches developed showed that it makes sense to address some topics without digital integration. On the other hand, it also became clear that a lot of data is already available in the MES, but that it is currently not used, or only used to a limited extent.

Table 3. Ideate Phase – Approach, Insights, and Reflection

Task	Purpose	Insights and reflections
Abstract solution	Identify ideas on possible solutions	- Change from reactive production environment to a more proactive environment via the use of data. - When asking "*how can I do better?*" practitioners have valuable insights.
Rating on digital shopfloor solutions	Search for matching solutions that can be realized with digital tools	- Most of the data-handling needed for the shopfloor services is handled through the MES. - MES (as described in VDI 5600) lacks functions in advanced analytics, prediction, and simulation.

4.5 Prototype

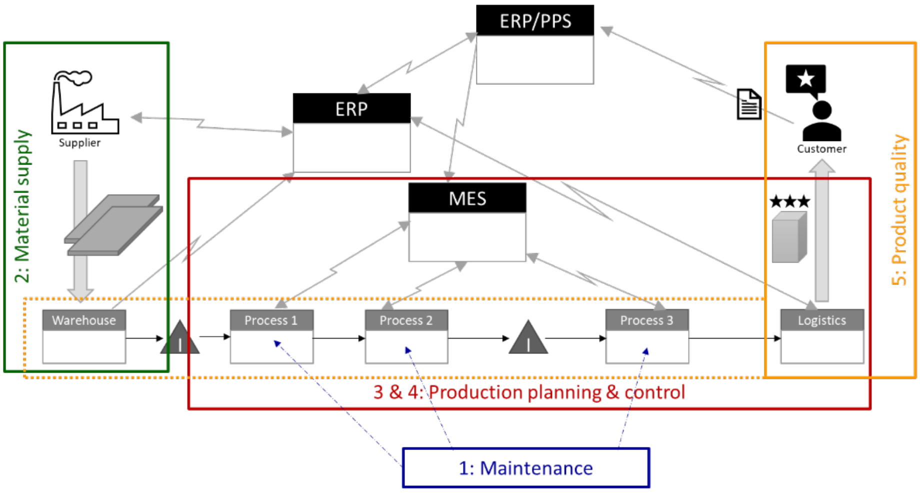
The aim of the prototype phase is to visualize issues through low fidelity prototypes, storyboards, wireframes, or other tools to further test, develop and discuss ideas [22]. For the creation of concrete use cases, visualization methods were used here. These are summarized in Table 4.

Detailed use cases were developed based on the abstract solutions from the ideation phase. Visualization supported the use case development and aided the classification of the use cases based on their type, in the form of a diagram. Selected scenarios were rated using the Industry 4.0 maturity index [10], which allowed detailed mapping of the scenarios, and in parallel, the development of a roadmap. The five use case scenarios are presented in Fig. 2.

Table 4. Prototype Phase – Approach, Insights, and Reflection

Task	Purpose	Insights and reflections
Use case development (21)	Grouping, use case identification, ideation	- Enabling data processing through analytics, prediction and simulation in production is crucial. This is missing in current MES requirements. - It is about empowering employees to make informed decisions, not to remove them.
Consolidation of scenarios (5)	Complementary use of use cases	- Model of Porter & Heppelmann and Schuh et al., delivered a good basis for developing a roadmap of use cases.

Fig. 2. Developed use case scenarios illustrated on the value stream



4.6 Testing

The purpose was to evaluate the results from the prototyping critically, and the approach, "*Prototype as if you know you're right, but test as if you know you're wrong*" [22, p. 170] was taken. Testing was completed on early paper-based prototypes, Table 5 summarizes the approach taken.

A slide deck of use cases was prepared to support the interviews. The internal and external interviews provided feedback on the cases and confirmation (or otherwise) of the assumptions used when creating the use cases. The interviewees' perspectives were summarized according to Mayring [24] so that results could be easily compared. A mind map was created to visualize the findings and to support the linking between input and subcategorization.

Table 5. Testing Phase – Approach, Insights, and Reflection

Task	Purpose	Insights and reflections
Preparation	Develop the interview case book	- Visual descriptions support the prototypes.
Internal interviews (5)	Verification of use cases with stakeholders	- Opportunities and risk to implement use cases. - Interview insightful but provided no uniform opinion on the prototypes.
External interviews (5)	Investigate and verify foundation and confirm assumptions	- Very different understanding of terms e.g., digital twin, smart factory, Industry 4.0. Process first, digitization second, & start small. - Practitioners having a hard time to define terms differentiating digital representations.
Summarization and revision	Summarize learnings and obtain confirmation	- Content analysis and categorization. - The categorization generated insights from the interviews and thus improved the prototype.

5 Discussion

The firm had limited experience in MES and smart manufacturing technologies, but more importantly, they lacked maturity in Lean manufacturing and process optimization which are the foundations of a successful manufacturing system implementation. Consequently, it was decided to capture the requirements by focusing on the apparent problems met in operational.

During the study, the foundations necessary to develop a shopfloor platform were supported by using an Industry 4.0 maturity index to assess the solutions developed. The higher-maturity, analytical micro-services [10] were found to be based on easily accessible transactional data from the system. Although some of the firm's operational technologies provide data, they are rarely used, as accessing the data was difficult. Developing and testing prototypes showed that a different understanding of terms exists, making it hard to derive precise requirements. However, testing the prototypes provided valuable feedback and overcame the differences in understanding. Following detailed evaluation of the needs, the firm decided to prioritize and phase the implementation by defining a roadmap that supported their ongoing needs. An important aspect to consider is potential future needs, to ensure that the chosen solution can scale with the firm and provide industrial agility. Further, this approach, when coupled with kaizen thinking, encourages suggestions for ongoing improvement at an operational level.

This work shows a possible approach to how Design Thinking [22] can be adapted and applied successfully within a ETO environment of an SME that has limited understanding of their requirements for Smart Manufacturing. It also confirmed that following a hybrid Design Thinking approach with the integration of Lean tools, which are well integrated into a production environment [11], allowed the firm to build a roadmap to further build and evolve such an MES. A properly applied MES then also facilitates the identification and elimination of waste which helps to increase operational efficiency further [18]. The integration of different perspectives gives the firm the opportunity to develop targeted and suitable solutions for a range of stakeholders. This was particularly important in the area of planning, advanced analytics, simulation and prediction, where digital tools can add even more value in the future [13]. The iterative approach and conscious expansion and contraction of the problem space as well as the solution space was a new approach for the firm. The study confirms that MES requires customization to individual businesses, and that MES must provide the shopfloor platform for additional Industry 4.0 functionality [1].

Reflecting on the research question, in this case an SME with limited experience in smart manufacturing can specify their requirements for a Smart Manufacturing system that integrates operational, tactical, and strategic requirements. The application of a hybrid Design Thinking/Lean approach supported the process of discovery and allowed an adaptable roadmap to be created forming the basis of the plan for the firm's Smart Manufacturing program.

The limitation of the work is that it was limited to one case and was reported before the implementation phase. A review should be made post implementation over a longer period to understand the value created. A multi-case study of firms using more traditional approaches should be undertaken.

6 Conclusions

This is only the first step for the firm in the digitalization journey to lead to Smart Manufacturing and ultimately to a Smart Factory. Using the hybrid approach, the firm has a roadmap that focuses on the short-term adoption of an MES and a longer-term version with increased levels of optimization and automation. This approach helps to understand the challenges faced and gain consensus. Missing from the approach was identifying the key metrics that can be used to measure the success of the implementation. This will help prove the value and confirm the initial requirements were covered allow the firm to build a solid foundation for the digitalization of their manufacturing process.

It is recommended that an action-research project is embedded within the digitalization to allow a longitudinal case study to be built up following the digitization efforts over two years. This would enable a detailed set of the lessons learnt to be abstracted from digitalization.

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