Development of a Lean Information and Communication Tool to Connect and Digitize Company Departments in Small and Medium-Sized Enterprises

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***Abstract*—Small and Medium-sized Enterprises (SME) see themselves confronted with constant challenges. Globalization, volatile markets and international competition require a focus on key topics such as customer satisfaction and delivery reliability. Key requirements for achieving these aims are lean and reactive business processes, which are obtained through horizontal and vertical networking. To network these business departments a lean shop floor information system, consisting of Smart Devices and a production application is developed. The aim of the system is the recording and needs-based communication of component modifications and technical drawings in SME special machine manufacturers. With the system, reduction of cycle time in projects, timely feedback of errors from the shop floor to the top floor, reduction of mistakes carried over to new projects and reduced time for the completion of the customer documentation can be achieved.**

Keywords-Lean Manufacturing Tool; Production-App; Smart Devices; Industry 4.0; Value Chain Digitization

I. INTRODUCTION

Small and Medium-sized Enterprises (SME) are facing many challenges and have to overcome these, in order to persist in the international competition [1], including challenges such as the individualization of the products and shorter product life cycles [2]. In response to these challenges in production, lean and reconfigurable processes are applied as a solution [3]. The required ability to react more frequently and flexibly can only be achieved, on correct and timely information [4].

Verbal and paper-based information exchange is the most widely accepted form of communication in SMEs even today. In particular, SMEs must accept these challenges, open themselves to new technologies and take advantage of it [11]. The introduction of new technologies is particularly difficult for SMEs, due to non-existent IT capacities and their high specialization in manufacturing and assembly processes of their daily business. In order to be able to react adequately to time-intensive factors, such as production changes and disturbances, it is necessary to develop lean solutions and find new ways to optimize and to digitize production based on existing IT facilities in SMEs.

The article focuses on the connection of shop floor and top floor, especially the connection of design/development department with production entities such as manufacturing and assembly. The presented industrial use case is the change of technical products and drawings during production in special engineering companies. Therefore, a production-app in combination with smart devices and lean processes was developed. Use case and procedure as well as the technical solution are mainly related to SME – machinery and plant engineering companies. Especially companies, which produce individual and special machines, mostly with batch size one, are designated for using the system.

The presented research and development is part of the research project NeWiP. In four different use cases the project analyses industry-related problems and develops solutions for the connection of company departments and production entities. Moreover, solutions for the connection between companies and information exchange are developed.

This paper is structured as follows: in Section II, an overview of related work is given. Furthermore, Section II describes the use case in detail and concludes with the advantages and aims of the presented procedure and the technical solution - the shop floor information application (SIA). Section III describes the procedure and used tools during the analysis of the initial situation. In Section IV the resulting requirements are described. Both analysis and requirement were taken into account during the development of the optimized process and the design of the production application. Optimized process and technical solution are finally outlined in Section V. It leads to the description of main functionalities of the developed production-app in combination with the smart devices in Section VI. Finally, Section VI concludes with a summary and gives an outlook on future work.

II. RELATED WORK AND PROBLEM DESCRIPTION

Efficient management of flexible processes is hardly possible without supporting systems and the provision of decision-relevant information [3]. Cyber-Physical Systems (CPS), Manufacturing-Executive-System (MES) and Enterprise-Resource-Planning (ERP) systems are designed to bridge the media gap between the physical and virtual world, providing up-to-date and comprehensive information. Components equipped with sensors, actuators and computing capacities can transfer information about themselves and their environment from reality to IT systems [5]. These CPS offer an opportunity to close the gap between the real world and the virtual world [6]. CPS gather physical data via sensors, control processing units and communication devices [7] [8]. By linking barcode, quick response code or RFID, the media gap between the object and information level can mostly be reduced [6].

The technologies associated with Industry 4.0 have not yet taken a comprehensive approach to production, especially in SMEs [9].

During industrial production, a variety of information, e.g., product-, process-, and project-related information occurs. For these types of information, there are several methods and systems of information gathering and exchange. At the shop floor area, information is transferred via verbal, written or computer-related communication. Production Data Acquisition (PDA), Machine Data Acquisition (MDA), Shop Floor Programming (SFP), Computerized Numerical Control (CNC) and Tool Management Systems (TMS) are the most frequently used computer-related applications in the shop floor area. Some systems have grown historically as isolated applications, without suitable interfaces that enable the integration of further systems. In addition, these systems are stationary and often not very intuitive. Declared goal of research and industry is a consistent shared use of data and a complete integration of all systems, as well as a uniform structure of information to ensure data exchange among each other [10].

The usage of CPS and digitalization is providing up-to-date and comprehensive information, which help to optimize the production process, to support employees in various company departments and to close media gaps between the physical and virtual world along the value chain. The focus is on socio-technical systems, in which people and machines are networked at different levels. Information are collected by means of suitable technical systems and software solutions. These are distributed to the respective specialists in a context-based manner so they are able to make their decisions.

A. Problem Description

The use case for the communication tool is the connection of shop floor and top floor departments in SMEs special machine manufacturers, where the transmission and recording of information is still largely paper-bound. The customer-specific special machines are planned in the design/development department. Then, they are manufactured, assembled and commissioned in the company's shop floor facility and later at the customer's plant.

During the execution of a project (development to commissioning of a special machine), a large number of employees of various business departments are involved. Main subject of the use case is the change process of technical drawings. For clarification, the process as it is today is described in the following: the design/development department creates the technical drawings, which are forwarded to the shop floor upon approval of the project leader in analogue form. Occasionally, design and drawing mistakes occur, which have to be corrected both on the product itself and the CAD data (3D and 2D data). Certain employees in the shop floor are qualified to make these alterations if it becomes necessary. These are handwritten on the technical drawings. At the end of the production process, all technical drawings of a project are transferred to the design/development department, in order to create the complete project and customer documentation. Since all of these technical drawings are received in the design/development department at the same time and after completion of the special machine, they have to be updated successively. This procedure is personal intensive and causes delays.

Moreover, handwritten changes on technical drawings increase the risk of media breaks between shop floor and design/development. During these projects, mistakes and errors have to be reported and corrected timely, so that they are not repeated in new projects. The result is that these mistakes might be carried over to new projects running in parallel, if the incorrect machine modules have not been updated in CAD programs in time. Figure 1 shows the initial situation and the aim of developing and implementing a production-app.

B. Objective

The objective of the communication tool SIA is the reduction of media breaks in the presented use case. On the technical side, this becomes possible by using Smart Devices and a production-app to digitize changes on technical drawings and modules. Furthermore, there are changes/adaptations of the business processes.

If technical changes and process adaptations are combined, new change/business processes become possible so that the design/development department is enabled to update (modules) changes simultaneously to the production process. This reduces the time until changes are noticed and - more important - corrected. So design mistakes on machine modules can be updated timely to their detection in shop floor, resulting in a reduced probability of repeating an error in new projects. Besides, it also improves the planning of required personal capacities in the design/development department.

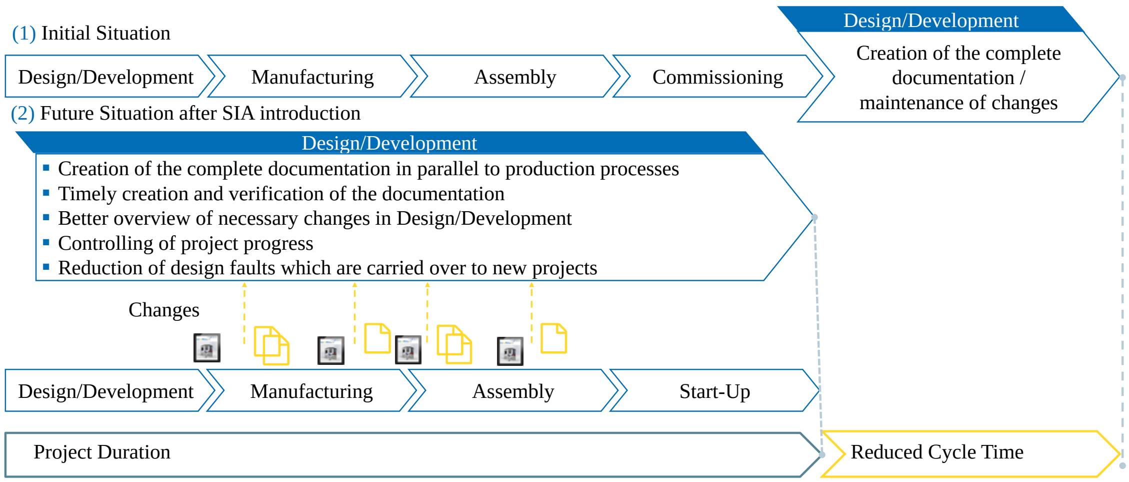

Figure 1: Advantages by using the shop-floor-information-application (SIA)

By directly digitizing technical drawings on the shop floor, media breaks are avoided. The shop floor information application (consisting of Smart Devices and production-app) provides necessary functionalities with the following advantages:

- Reduction of cycle time of a customer project
- Timely feedback of errors from shop floor to top floor
- Reduction of mistakes carried over to new projects
- Improved planning capacity in development and design/development department
- Reduced time for the completion of the customer documentation

III. Analysis of the Initial Situation

In the development and production of special machines, interdisciplinary project-teams are involved. Especially in interdisciplinary teams, it is not guaranteed that all participants will understand a statement in the same way. Therefore, a uniform understanding of the initial problems and requirements is necessary. A starting point is constituted by a user-story. In the development phase, the project objective is divided into definable and independent subgoals, which are described in an easy and understandable way [12]. Acceptance criteria should be identified and named, in order to increase the willingness of users for technological change. Acceptance criteria are for instance ergonomics, mobility, robustness and tolerance. During the development of the technological solution, these acceptance criteria must be noted and their degree of performance should be checked. In addition to these criteria, quality requirements should be identified and named. These requirements describe the features of the system to be developed according to ISO / IEC 9126. Characteristics such as functionality, reliability, usability, efficiency, maintainability and transferability have to be considered.

Nowadays, information should be provided at the right time, in the right place and in sufficient quality to the user. Therefore, lean and smart production processes and short information flows within the organization are needed [13]. Real improvements in business-, core-, support- and management processes can only be achieved if current processes and information flows are analyzed. The main reasons for modeling of the actual state are following:

- The modeling of processes is the starting point for the detection of weak points and the elaboration of improvements.
- Without an accurate understanding of the actual process, fault causes and possible potentials for improvement cannot be localized precisely.
- The documentation of the actual state generates process knowledge, which is available to all project participants.
- Media breaks can be better recognized.

The scope of analysis is always project-specific. There are among others four survey methods for analyzing the actual situation. In advance, by viewing and analyzing all process relevant documents, a high degree of information can be generated. Often, documents are created regarding to certifications DIN EN ISO 9001 and are already existing. By analyzing the value chain, beginning from shipping area on to receiving area, further process relevant information is gathered through observation and interview of the process owner. In team workshops, more detailed information about specific production processes and information flows can be acquired. Open questions and further issues can be discussed. In specific single interviews with employees, remaining questions can be answered and high detailed knowledge about processes, production as well as information and material flow can be collected.

A variety of different languages for process modelling are available. Common modelling languages are for instance Event-driven Process Chain (EPK), Unified Modeling Language (UML) or Business Process Execution Language (BPEL) or Business Process Modeling Notation 2.0 (BPMN2.0). BPMN2.0 was chosen for the use case because it is suited for the requirements of a structured and formalized mapping of business processes and information flows. In this language, activities, gateways and events are

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represented by BPMN basic elements. Primary goal of the BPMN2.0 is to provide a notation, which is easy to understand for all participants in business process management [14]. During analysis of the initial situation, the BPMN2.0 was used to document the current business processes in an understandable way for the project team. With an analysis of the important business processes for the project, the future business process was developed in BPMN2.0, so everyone in the project team got a clear view of the future business process and the requirements and functions for the production-app. Moreover, the documentation in BPMN2.0 is understandable and expressive enough to be used in future DIN EN ISO 9001 documentations.

Following the analysis of the current state, the requirements for the system and the app as well as the Smart Device are derived.

IV. Requirements to the System

The following fields of action, such as the mastery of information and communication technologies, the economic introduction of new technologies and processes, the involvement of employees in this new form of industrial production, have become key success factors.

Challenge - Information Technology: IT-systems are developed to support business processes and production processes. Due to constantly changing influencing factors, an adaptation of these systems is indispensable. However, it is difficult for producing SMEs to cope with necessary changes in complex programs and architectures because of their own limited resources and their high specialization in manufacturing and assembly. This circumstance has resulted in isolated applications that are optimally suited to the execution of a specific business process, but can only be integrated into the IT infrastructure of the company in a highly resource-intensive manner [11]. Therefore, a requirement of the developed system and application was the integration into an existing architecture without endangering other systems.

Challenge - Cost-Effectiveness: The key factors of production, labor, land and capital, are some of the input factors of any industrial production. The output, on the other hand, is e.g., simply valued over the product price. The desired transparency and responsivity, a key target of industry 4.0, is achieved only on the basis of information. Information as such is not quantifiable and does not represent a typical characteristic for the economic consideration of an investment project in producing SMEs. Collection of context-related information on the shop floor is the main function of the developed system. For the economic assessment of the system, quantifiable factors such as improved personnel utilization, reduced error avoidance of the same components and a shortened project running time can be mentioned.

Challenge - Employees: Industry 4.0 introduces a paradigm shift to an enhanced network of intelligent production technology. The main focus of this development is the human being, as a link between process and equipment. This human-machine interface requires a rethinking of all existing forms of work organization and efficient workplace design. In order to meet the requirements of an efficient workplace design, factors such as user characteristics, environmental factors, social and organizational environment, factors of work tasks, as well as factors of work equipment were taken into account in the development of the system [15]. On the basis of this, a prototypical conceptual design (drawing, low-fidelity prototype and high-fidelity prototype) took place. Particular attention was paid to the creation of an ergonomic human-machine interface and a lean integration of the system into existing business processes as well as a lean design of main functionalities for the multimodal gathering of information. In the design of the main functionalities, the seven principles of dialogue design, task adequacy, self-describability, controllability, expectation conformity, fault tolerance, individualization and learning support according to DIN EN ISO 9241-110 were considered. Further methods like discussion-, simulation-, version-, and prototyping methods can be of use for the participation of users in software development and increasing the willingness for using the new system. In order to evaluate the design, functionality and content in an early phase of the project, the solutions are implemented in different prototypes. With increasing project progress, the prototypes change in kind of their build effort. Therefore, low-fidelity prototypes were developed at the beginning of the project. This type of prototyping is relatively resource saving and allows short and low time consuming changes in the design [16]. The design was developed with the standard software Microsoft Visio. Even before programming the app, all responsible users could discuss the rudimentary functions. In further iterative loops, the design and functions could be changed with low effort. After the rough plan period, the application was build up in detail. These are high-fidelity prototypes and illustrate precise functionalities and structures as well as the design of the application. Therefore, the prototype software Axure was used.

V. Concept of the Communication Tool

After an initial state- and requirements analysis a concept for networking shop floor and top floor area was developed. By using the system, employees can be supported during their daily work, without additional burden or additional processes, physical and ergonomical restrictions. The developed system and its application in the business process are shown in figure 2. The optimized process in business departments of the treated use case follows steps (1) to (6):

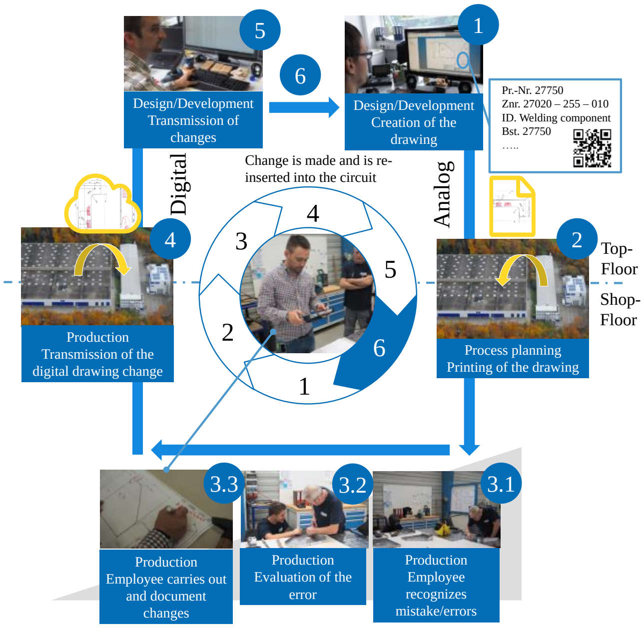

Figure 2. Optimised process by using the production application

(1) In design/development department, an auto-ID code (QR-Code and Dot-Paper) for the technical drawing has to be generated. The printed pattern consists of small dots whose diameter is 100 µm. By the combination of these points and their position at the intersections of a four-sided right angle grid, coordinates can be formed. This allows the Smart-Pen to determine position on the paper [17]. In Smart-Pen a camera is integrated, which record and protocol movement of the Smart-Pen. The generation of the QR-Code is done automatically. This is achieved by a developed plug-in for computer aided design programs (e.g., Solidworks, NX, Inventor, AutoCAD). The QR-Code contains relevant information such as the drawing number, project number, name and index of the drawing and is used for identifying the technical drawing via Smart Device. By means of the QR-Code, which is printed onto the analogue technical drawings on the shop floor, analog technical drawings can be digitized by reading the machine-readable code with the Tablet-PC without much effort.

(2) The approved technical drawings are stored in the operational data management system and provided to the work preparation as a PDF file. In the work preparation department, the technical drawings of a project are still printed out and placed in a project folder. The analogue version is often still a must-have in shop floor. With this restriction several ways to document a virtual twin are possible, see chapter VI. This analogue project folder runs through the production and serves as a sole work instruction for the worker. The digital twin of the technical drawing is stored and can be used any time after QR-Code scan.

(3) Hand-picked employees are equipped with the Smart Device (Tablet-PC), Smart-Pen and the production-app. When the employee makes a change to the components and to the technical drawing, as described in the application scenario, he/she has several functions to document the changes. After a personalized log-in to the application, the operator scans the QR-Code with the camera of the Tablet-PC. The QR-Code scan loads the digital twin and further information of the technical drawing. The application provides the employee with four multimodal functionalities, to document the changes on the parts or technical drawings: Smart-Pen, Tablet-Pen, Take Picture, 3D-Model.

After documentation, there are an analogue and digital twin of the technical drawing. The analogue version runs further with the modified part through production, whereas the digital version is forwarded to the design/development department for documentation and correction.

(4) The employee finishes the changes and sends the digital technical drawing with its changes to the design/development department by using a predefined mail.

(5) In the design/development department, the incoming information includes the technical drawings as well as a description of the problem and the priority. These are sighted by the manager of the department and arranged according to their urgency. With this information, he/she is able to improve capacity planning and can direct the changes to employees according to priorities and available capacities.

(6) The design/development department maintains the modifications. After this, a new release of the mechanical drawing and CAD data is stored in the Operational Data Management System. The work preparation department has now access to the blueprint`s PDF-version and is able to attach a printed copy of it in the project`s file folder. Furthermore, all relevant changes are done and CAD data is updated for new projects.

VI. FUNCTIONALITES OF THE APPLICATION

To achieve the above mentioned change process, the production-app is developed, offering several functions, which are described below:

Through specifications and requirements as stated in the previous sections, several functionalities like Tablet-Pen, Take Picture, Smart-Pen and 3D-Model were included in the production-app as shown in Figure 3. After a first log-in of the employee on the app, the secondary function QR-Scan (1) is executed. The employee moves the Tablet-PC over the QR-Code on the technical drawing. After identification, a data download of the digital technical drawing (the virtual twin) from a server to the temporary memory of the Tablet-PC is carried out. As a result, the previously analogue drawing is loaded and visualized on the Tablet-PC. At this point, the user has the option to choose between the main functionalities (2) Tablet-Pen, (3) Take Picture, (4) Smart-Pen and (5) 3D-Model. After the information has been completed by one of the main functions, the changes noted on the technical drawing are sent to the development/design department. The transmission of the information is performed by the secondary function (6) Send Email.

(1) Scan QR: The QR-Code is used to digitize analogue technical drawings on the tablet by reading the code on the drawings. The QR-Code is generated in the development/design department. It is associated with the technical drawing and has information about the project, drawing, etc.

(2) Tablet-Pen: With the functionality, the employee can process the technical drawing using a Tablet-Pen. Via a Tablet-Pen, the employee can perform the following elementary tasks according to DIN EN ISO 9241-420:2011: drawing, accurate pointing, fast pointing, selecting and pulling. After the completion of the information gathering, the technical drawing, including all changes, is sent to the design/development department via email.

Figure 3. Main functionalities of the production-app

(3) Take Picture: The Take Picture function module allows the employee to capture images from the technical drawing. It is conceivable that he takes a snapshot of a component that is still in production. The image of the component can thus be coupled with the technical drawing. After confirming the suitability of the recording, the image appears on the Tablet-PC's user interface. The picture is automatically provided with the recording date and time. Thus, a later termination of the recording is possible. Analogous to the Tablet-Pen function, alphanumeric information can also be recorded here.

(4) Smart-Pen: Handwritten changes on an analogue drawing are immediately digitized by the Smart-Pen. When the change has been completed, the specialist can view the change on the Tablet-PC. In turn, the digital twin can be further prepared with the surface pen and sent to the development and design department. The Smart-Pen is based on a common ballpoint pen. When the pen is placed on the paper, the ink mine leaves an ink trace on the paper. Simultaneously, the data is recorded as soon as the Anoto-patterned paper is being written on. The pencil records each stroke and point as it is made by the employee, and then transfers the data to the processing system [17]. The data is stored on the pen until it is transferred to an FTP server via a docking station. If there is a need for a change in the drawing by the employee, the changes on the technical drawing are recorded (drawing is provided with Dot-pattern) with the Smart-Pen. After completion of the handwriting modification with the Smart-Pen, a digital twin of the analogue technical drawing is generated on the Tablet-PC.

(5) 3D-Model: This is a functionality to provide the employee with additional information of the machine component in manufacture or assembly. This function loads a 3D-Model of the component onto the Tablet-PC. The model can be changed in size and orientation by the employee.

(6) Send Email: Communication between the employee and the developer/designer takes place via the standard e-mail account (Microsoft Outlook) of the employee. A content system is integrated into the function module in order to spare the employee the writing of an email and to ensure a standardized information content of the email. The employee is given the opportunity to define the responsible persons, the originator of the changes and the urgency of the change by means of two dialog windows. With this standardized information system, the employee can finish and send his report with three clicks in the production app. The email is received by the design/development department manager. The information gives him an overview on changes in the project. Considering all information and current projects, he can perform his capacity planning for his team. In the future, the production-app shall be extended with a capacity planning tool.

VII. Summary and Outlook

The presented shop floor information application, which consists of Smart Devices and a production-app is developed to gather changes on the shop floor in real time and communicate these to organizational departments.

The system targets at first the design/development, in which a QR-Code is generated. The QR-Code is copied on the digital technical drawing by a plug-in in the four software-supported CAD programs used. The QR-Code is a qualifier to digitize the analogue technical drawings on the shop floor without much effort. In addition, a so-called dot-paper is created in the design/development. By the dot-paper a further form of digitization is provided via the Smart-Pen. Accordingly, the technical drawing is provided with two auto-ID codes for digitization. In production planning, the analogue technical drawing is printed for the run through reduction. If the employee has to make a change to the components or to the technical drawing, he uses a Smart Device (Tablet PC) to scan the QR-Code. A lean developed application is installed on the Tablet-PC, which provides the employee with four functionalities for gathering and communicate changes to the components. The aim of SIA is the reduction of media breaks between shop floor and top floor. The digitization results in improvements by timely creation and verification of the device documentation and reduction of design faults, which are carried over to new projects. Furthermore, creation of the complete documentation in parallel to production processes and controlling of project progress will be possible.

The shop floor information application will be implemented in future in the company. During implementation phase, the system and processes will be evaluated and adapted iteratively. Results and experiences of the use case will be used to develop the system further and to refine methods for networking and digitizing of the value chain.

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