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Procedia CIRP 61 (2017) 487 – 492

www.elsevier.com/locate/procedia

The 24th CIRP Conference on Life Cycle Engineering

Benefit oriented production data acquisition for the production planning and control

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Abstract

In order to stay competitive, many manufacturing companies, especially small and medium sized enterprises (SME), face the challenge to transform their production and the corresponding production planning and control (PPC) processes for the upcoming Internet of Things (IoT) Era. Since their time and cost budget is a constraint, SME need to focus particularly on relevant data types, data acquisition points and technologies that will be beneficial for their manufacturing processes. State of the art approaches are lacking in supporting SME sustainably, systematically and company-specific on their way to IoT from a PPC-perspective. Therefore, in this paper a systematic approach is described, which is providing a sustainable, benefit-oriented, and gradual guideline for companies which aim to build an IoT-supported production data acquisition for PPC processes, in order to enable sustainable manufacturing. The developed method is taking into account company-specific production structures through quantitative key performance indicators and qualitative morphological checklists. With the help of the approach proposed in this paper, SMEs are supported systematically on their transformation path of the production data acquisition for the PPC into the IoT Era in order to enable a sustainable production.

Peer-review under responsibility of the scientific committee of the 24th CIRP Conference on Life Cycle Engineering

Keywords: data acquisition, production control, traceability

1. Introduction

Sustainable manufacturing in high-wage countries can only be achieved through an efficient production planning and control (PPC). In order to enable a well working PPC, a reasonable data base with company-, product- and production related data is needed. Especially many small and medium sized enterprises (SME) are lacking the knowledge concerning relevant data types, data acquisition points and technologies that will be beneficial for their PPC in the context of their manufacturing surrounding. Even with big data analysis, companies can not plan and control efficiently if they are lacking relevant input data. Since current approaches do not cover the defined issue, in this paper a systematic approach is described, which is providing a sustainable, benefit-oriented, and gradual guideline for companies which aim to build an IoT-supported production data acquisition (PDA) for the PPC, in order to enable sustainable manufacturing.

2. Data needs of PPC and ICT for data acquisition

Due to volatile market demands and a wide variety of variants, the planning and controlling processes are a very important and complex task for ensuring a high adherence to promised delivery dates. One widespread framework for the PPC is the Aachen production and control model. It is highly orientated on the logistic objectives, as it aims to increase flexibility, adherence to delivery dates, capital utilization and to decrease throughput times and work in process [1]. It distinguishes between network, core and cross-sectional tasks, whereby in-plant PPC is one part of the core tasks [2]. This core task itself consists in turn of three tasks which are mainly responsible for the detailed controlling process and is described in the following. The order release determines the point in time when an order is processed to the production and triggers the provision of required materials. Sequencing defines for each workstation which order should be processed

Peer-review under responsibility of the scientific committee of the 24th CIRP Conference on Life Cycle Engineering
doi:10.1016/j.procir.2016.11.142

next. The job of capacity control is to determines the actual capacities usage and decides about extra hours and staff distribution. [3]

Since the mentioned tasks are strongly connected to the shop floor, a high traceability and resolution of production processes is of high importance to enable efficient PPC processes. Depending on specific controlling methods, each task requires different information that should be collected on the shop floor. For that purpose, many information and communication technologies (ICT) are available on the market. Typical solutions to acquire feedback from the shop floor automatically are barcode and radio-frequency identification (RFID) technology which pertain to the group of auto-ID solutions. Other comparatively cheap technologies for PDA are e.g. OCR, terminals, beacons or cameras. PPC related production data such as the starting or the end time of setting up a machine, can be collected through workers scanning barcodes on production orders or through RFID sensors recognizing a transponder within their reading area. Whereas barcodes are already commonly used, RFID solutions gain increasing popularity, especially because of easy handling and higher data storage. The big disadvantage of the RFID technology is its perturbation in metallic surroundings. An even higher information resolution than with RFID can be gained through real time localization systems (RTLS) that are mostly based on Wi-Fi and enable a continuous traceability of objects through the entire production. The drawback of RTLS technology is, that compared to barcode or RFID technology it is quite expensive and bulky.

The transformation process of the production and the corresponding PPC for the upcoming IoT era should take both -the specific data needs of different PPC methods and various ICT collecting consistent data from different sources - into account.

3. Existing approaches

In this chapter, existing approaches which deal with the implementation of a PDA-system are reviewed. The approaches can be classified in four different categories: (1) generic implementation approaches, (2) approaches to implement IoT, (3) concepts to implement specific ICT, (4) approaches to improve the PPC. The approaches are assessed whether they have a guideline characteristic and take PPC of SME into account. Furthermore, it is checked whether a wide range of ICT is considered and whether data acquisition points and the specific data to be collected is defined.

(1) Generic implementation approaches

Within this category, general project management concepts such as Kuster [4] and DIN 69901 [5] were analyzed. Both approaches, but especially the project management standard, are powerful tools to structure and organize the implementation process and help to set a timescale for the whole project.

(2) Approaches to implement IoT

There are many different existing approaches, which deal with the implementation process of IoT. The approaches of Rauen et al. [6] and Chabanne et al. [7] were analyzed and assessed. All authors give a generic view on the topic by considering a large variety of different ICT such as embedded systems, Human-Machine-Interfaces or software systems. Moreover, all authors deal with the topic on a very abstract level and do not discuss the issue of the implantation process itself.

(3) Concepts to implement specific ICT

Fuhrer & Guinard [8], Vasishta [9], Poirier et al. [10], Jones and Chung [11] and Fruth [12] focus their research on the implementation process of specific ICT. In many cases, this is the RFID technology. Whereas the majority of the analyzed approaches address the topics of production and logistics, e.g. Fuhrer & Guinard as well as Vasishta deal with topics from outside the subject area. Although the mentioned approaches do not consider the large variety of different ICT, they give useful hints how to deal with the implantation process itself.

(4) Approaches to improve the PPC

Within the last category, the approaches of Ostgathe [13], Stuermann [14], Zhang et al. [15], Engelhardt [16] and Schuh et al. [17] were assessed. All authors create a strong reference to the PPC and aim to improve the planning and controlling in enterprises through different strategies. In order to deal with the high complexity of the PPC-process, almost all approaches highlight the importance of real-time PDA. On the one hand, approaches within this category are highly relevant due their strong relation to PPC. On the other hand, authors neglect the implementation process itself as they do not show necessary steps depending on specific enterprise characteristics.

Conclusion

In total, the assessment shows that none of the reviewed approaches offers a holistic solution for the benefit oriented implementation of ICT to enhance real-time PDA. Either the approaches are too abstract and only on a generic level or they are too specific by focusing only on single ICT. Furthermore, the majority does not consider the influence of different characteristics of the shop floor and its surrounding and the impact on the level of data resolution that is needed. Last but not least there are no guidelines concerning the positioning of data collecting points.

4. Approach to build a benefit oriented PDA-system

4.1. Overview

The approach to implement a benefit oriented PDA-system for the PPC is shown in figure 1 and consists of four main phases: preparation, current state analysis, target state definition and assessment. Each phase consists of several sub-phases, that are explained in detail in the following paragraphs.

The selection and implementation of a PDA-system is a complex process, which poses a great challenge for SME. In order to cope with the implementation successfully, it is advisable to merge the process into a project. This is followed by the modularization of the shop floor, which is an important step for the next phases, because it ensures a targeted PDA through manageable sections. Through the modularization, the entire production system is broken down into modules that can be controlled in an easier way. Each module will be analyzed for its individual data needs so that a fitting PDA-solution can be found.

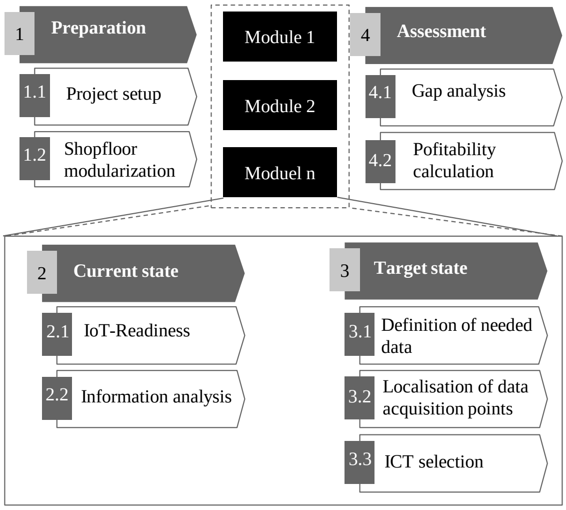

Figure 1: Approach to build a benefit oriented PDA-system for the PPC

The following current state analysis and target state definition are the main part of this approach. These two phases are module specific, while the preparation and assessment phases are dealing with the whole production. The current state analysis and the target state definition are substantiated through four description and explanatory models, that have been developed during setting up the approach. An overview about the models is displayed in figure 2.

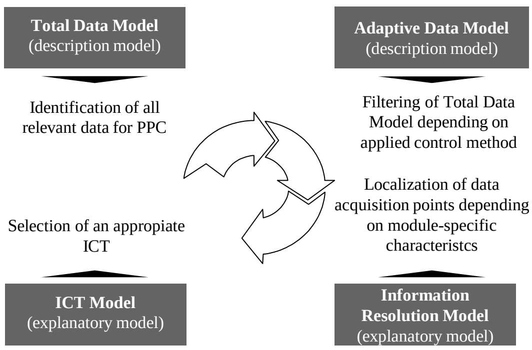

Figure 2: Theory models of the phase 2 and 3 of the approach

To outline the current state, the concept starts with the “Total Data Model” (TDM), which is a description model and contains a large amount of production data types in order to identify relevant data for the PPC. On that basis, the second model, which is called “Adaptive Data Model” (ADM) filters the totality of all data depending on the applied PPC methods in the considered module. By executing these first two models users can answer the question: ‘Which data should be collected in the modules?’. In contrast, the “Information Resolution Model” (IRM) helps answering the question: ‘Where should PDA take place?’. Through detailed consideration of module-specific characteristics and the related impact on the information resolution, the explanatory model enhances users to determine positions of data acquisition points. As a result of the first three models, a requirements profile can be created. This profile constitutes an input for the “ICT Model”. The model takes data-specific and cost-benefit aspects from selected ICT into account, so that a custom, benefit oriented PDA-system can be presented as a result.

The concept concludes with the assessment of all elaborated solutions. For that purpose, a gap analysis is performed at the beginning, in which potential existing PDA-systems are compared to the developed target state. Two specific gaps can be divided: a technology gap, that describes the deficit of the current ICT-solution and a data gap, which shows important additional data to be collected. The last step of the approach is a profitability calculation, that also considers specific issues of an IT-investment, like the hidden cost-benefit ratio.

4.2. Total Data Model

Around manufacturing processes, typically dense internal and external informational networks are formed in every enterprise [18]. Despite the name “Total Data Model”, the TDM does not consider the totality of business data but any data with regard to PPC. The main objective of this model is to structure the huge amount of data and classify it into categories, in order to enhance users to describe the current state of PDA. In literature there are three approaches to structure PPC data: (1) usage and monitoring data, (2) planning, actual and event data, (3) master and transaction data. Master and transaction data is one of the most common approaches and also the most suitable for that particular purpose so that the data structure in the TDM is built on it. Thus, on the first level the model distinguishes between master data which do not have a time-relation and are saved permanently in the system and transaction data which stem from master data and have limited lifetimes [19]. Based on this distinction, three more levels of aggregation are formed in which over 140 various data types are classified. Whereas, within the master data material masters, bills of material, resource data and work plans are distinguished, the transaction data contains inventories, requirements and operational data. The TDM includes all relevant data for PPC and serves as a checklist to assess the current data base and its accompanying PDA. For this purpose, it is not sufficient to check whether a specific data type is collected. Instead, it is further important to assess the quality of the data, since data quality is in many cases insufficient despite automatic data acquisition. It is important that all data and information is contextual, intrinsic, representational and accessible, which is also known as the four dimensions of information quality [20]. Assessing the information quality is one of the major steps to describe the current state of each module.

4.3. Adaptive Data Model

The ADM is mainly based on the TDM, since it uses the previously described data structure as an input. Even though the TDM only contains PPC-relevant data, the data requirements of the PPC for each module vary according to plant specific characteristics. Especially SME are confronted with large amounts of data, which are difficult to manage and do not generate an adequate benefit for the PPC. Therefore, the main objective of the ADM is to enable a benefit oriented PDA-system by using a "data-filter" that shows relevant data within the production modules depending on different tasks of the PPC. For this purpose, the ADM considers the data requirements of order generation, order release, sequencing and capacity control which are the four main tasks of production control. At first, very relevant data are highlighted for each of the four mentioned tasks regardless of specific PPC methods. To ensure a benefit oriented PDA, it is furthermore important to differentiate between various PPC methods. For instance, it makes a huge difference whether orders are released immediately, by planned start date (almost no feedback data needed), by work in process or by load of the workstations (many real-time feedback data needed). Accordingly, as a second step all data are filtered again depending on the specific PPC method within each module. Due to the large number of different PPC methods, the focus is put on the most common methods, such as constant work in process, workload control, first-in-first-out or plan oriented capacity control. For the purpose of visualizing this relationship, a matrix is used, in which 20 different controlling methods are examined for their specific data needs. Additionally to a qualitative statement, the ADM also makes a quantitative link between data and PPC methods, in order to give information about their respective importance. The analysis of the relationships is mainly based on PPC-literature and expert knowledge and is conducted as generic as possible. On the one hand, the ADM enables users to identify benefit oriented data needs of specific PPC methods, on the other hand it also provides some first hints on the positioning of data acquisition points. For instance, in a module where orders are released by bottleneck control, data collecting points must be positioned at the beginning of the production line and directly behind the bottleneck. For an exact positioning that is based on a benefit oriented data resolution, further module characteristics need to be considered, which is conducted in the following model.

4.4. Information Resolution Model

For the purpose of determining locations of data acquisition points, production modules and their borders are used as an input in the first step. Some existing approaches in the literature take the module borders as a key starting point to place data acquisition points. For instance, Engelhardt suggests in his approach to collect data on all module borders by using the RFID technology [14]. Based on this idea, so called "obligatory-acquisition-points" shall be placed on all module borders, so that incoming and outgoing materials are tracked. Nonetheless, the mere positioning of obligatory-acquisition-points is not sufficient for a real-time PDA in the majority of cases. In certain circumstances, specific module characteristics necessitate placing so called "optional-acquisition-points" to increase information resolution within the modules (see figure 3).

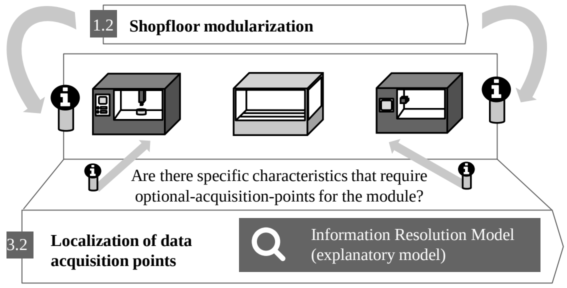

Figure 3: Acquisition points as a result of the IRM

Since the decision regarding further data collecting points is nontrivial, the IRM provides various factors which have a significant impact on the needed information resolution of the PPC for managing modules. The objective is to find the reasonable information resolution that provides the greatest benefits for PPC. In literature, there are already approaches that identify cost or complexity drivers in logistics and production. Although, none of them deals with factors that have an impact on information resolution, findings of these approaches can be transferred to the IRM. For the development of the IRM, a large variety of factors was researched and examined for their impact on information resolution. On the first aggregation level, the model distinguishes between six different factors: monetary, personnel, logistic, infrastructural, qualitative and key manufacturing factors. Each category contains various factors that are described in respect of their possible characteristics and the associated influence on the needed information resolution. As a result, 25 determining factors are described in a morphological box which enables users to make decisions regarding optional-acquisition points for each individual module. For instance, one determining factor of the logistic category is the lead time. Here, the explanatory model advices to increase information resolution in case of high lead times, whereas in case of short lead times obligatory-acquisition-points are sufficient. Since some factors like production principles and amount of variants lead to contrary directions, users should also prioritize the factors depending on company-specific characteristics. For instance, the IRM suggests a high information resolution in case of a flow production and a large variety of variants. But in practice, products with many variants are mostly processed in other production principles like a job shop production.

4.5. ICT Model

The selection process of suitable ICT is the last step to describe the target state. The considerations in chapter two have shown the large variety of ICT available on the market which all have different advantages and disadvantages depending on specific use cases. In order to build a benefit oriented PDA-system, it is necessary to take different ICT during the selection process into account. Based on the results of the first three models, a requirements profile can be created to evaluate the suitability of different ICT. First of all, the ADM enhances users to identify benefit oriented data needs of specific PPC methods so that a suitable ICT should be able to collect those data. Moreover, the IRM took specific characteristics of each module into account to determine positions of data collecting points. Suitable ICT should fit to those characteristics. To take both requirements into account, the IRM links between common ICT, the TDM and module-specific characteristics. Because of the huge variety of available ICT, only some common technologies such as machine data acquisition, barcode, RFID or RTLS have been considered in the approach. On the one hand, the ICT model assesses the ability of different ICT to improve data quality for each of the 140 data types of the TDM. Whereas, for transaction data the evaluation focus is on data acquisition, for master data administration aspects in focus. On the other hand, the ICT model compares ICT to determining factors of information resolution and assesses the respective suitability in the context of cost-effectiveness criteria. Primarily, those criteria are manufacturing principles, types of production, part flow, product value, area and degree of automation of the considered production module. The intention is to avoid solutions which guarantee high traceability but never pay off because of high investments. For instance, a RTLS solution in a small module that produces standardized products in manual work would go far beyond the actual objective.

5. Prototypical Application

In the following, the developed concept is validated in a prototypical application. For this purpose, the approach is applied on the in the Demonstration Factory Aachen (DFA).

On a usable space of approximately 1.600 m^2, complex relationships between logistic, production and other services are researched in the DFA. The plant is characterized by a highly adaptable layout and a scalable assembly system so that it reflects typical characteristics of production sites in a high-wage country like Germany. The DFA is mainly used to produce prototypes of bodies for electric vehicles and pedelec carts. The described infrastructure is particular suitable for research on IoT. As described before, the main part of the approach which enables a benefit oriented PDA consists of two phases. Due to limitation of space, the prototypical application is focused on these phases.

Figure 4 shows the structuring of DFA, including five different production modules.

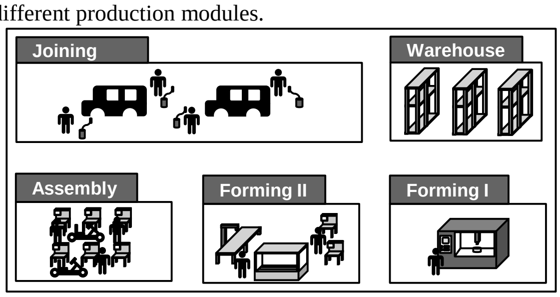

Figure 4: Modularization of shop floor of the DFA

Starting point for the orders is the high bay warehouse, which is also responsible for incoming and outgoing goods. From here, metal sheets are processed through the modules “sheet metal forming I & II”, where they are laser cut and bent. Depending on the intended purpose, metal sheets either go through the joining or assembly module. For each of the mentioned modules, the four models need to be applied, which is limited to the assembly module for the purpose of this paper.

First of all, the current state of the module needs to be described which is mainly realized by the TDM. In case of the assembly module, orders can be tracked through RTLS that is installed on cart frames. Even tough a very modern information system is installed here, the data quality of various data types is insufficient which was easily detected through the developed data checklist. The analysis of the current state has shown, that the majority of important data is collected but it is neither intrinsic nor accessible. This includes very important data types, like incoming and outgoing orders or the starting and ending time of assembly operations. The main reason for this is the missing system integration of various ICT so that many information structures have grown unsystematically over time.

After describing the current state of PDA, the target state of the assembly module can be concluded which starts with conducting the ADM. Within the considered assembly module, orders are released by planned start dates and sequenced by first-in-first-out principle. For the purpose of capacity controlling, a backlog control is applied (see schematic ADM visualization in figure 5).

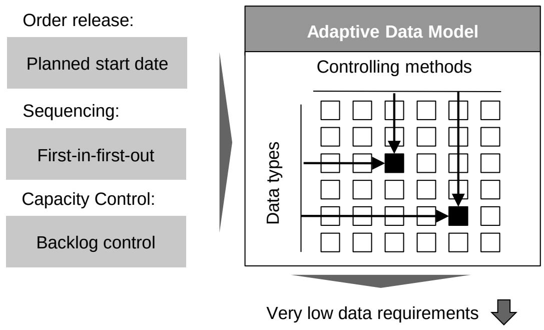

Figure 5: schematic visualization: Application of ADM in the DFA

This specific production control configuration has very low data requirements. Through the link between data types and PPC methods, the ADM is able to highlight the most relevant data types for each PPC method. Whereas for the order release, planned start dates should be tagged reliably on orders, the backlog control requires precise information about actual and planned output. The sequencing method does require also detailed PDA.

In the next step of the method, decision support regarding the information resolution of the module is needed. Through the developed morphological box, 25 characteristics are taken into account to determine a cost-optimal information resolution. On the one hand the focused module has factors, like a flow production or a very high share of value creation that justify the additional positioning of optional-acquisition-points. On the other hand, there are also reasons for keeping the information resolution lower, such as a very low degree of automation or a single and small series production. Taking all factors in a comparison of pairs into account, it is advisable to implement a higher information resolution because of cost-benefit aspects. Therefore optional-acquisition-points should be installed.

The last step is to select suitable ICT for the PDA-system-For this purpose, an excel tool is used that assesses the ability of ICT to improve various information qualities and also considers economic aspects. Taking only the data aspects into account, the ICT model suggests the use of RTLS as it promises the highest data improvements. But, with regard to a benefit oriented data acquisition which is linked strongly to cost aspects, it is recommended to use passive RFID technology in this case. Crucial factors for this decision are the small area of the module and the small batch sizes so that a RTLS use is not economically viable.

6. Summary and further research

In this paper, the approach to implement a benefit oriented PDA-system was introduced. Ensuring the benefit orientation through process orientation, taking into account different PPC methods as well as production settings and ICT to collect data, the systematic approach helps enterprises and especially SME to stay competitive in the IoT Era and enables a sustainable manufacturing processes. The approach consists of four main phases that also include the application of four models. Through the module based approach, the specific characteristics and data needs of each module are taken into account so that the final result is highly benefit oriented.

The next step is to conduct further research about each presented model. The developed relations between data needs of specific controlling methods and the localization of acquisition points should be validated in further prototypical applications.

7. Acknowledgments

The authors would like to thank the German Research Foundation DFG for the kind support within the Cluster of Excellence "Integrative Production Technology for High-Wage Countries".

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