Short-term cyber-physical Production Management

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Abstract

For most manufacturing companies a high adherence to delivery dates is their main logistic target. In consideration of the fact that for example material and information flows in production plants are getting more intersected and networked than ever before and customer demand tailored products in short throughput times, keeping an overview as well as responding properly becomes a huge challenge for the production manager. In the paper the new approach of cyber-physical short-term assistance of the production manager will be described. Its goal is to support the production controller by providing prioritized short-term actions through new sensor technologies, big data processing and simulation. The paper will outline how the roadmap to short-term cyber-physical production management is developed and what the real benefit for the production manager will be. With the help of intelligent visualization the application will display the effects of a performed action therefore be an optimal basis for decision for the production manager.

Keywords: Information management; production control; simulation

1. Introduction

A high adherence to delivery dates is the main logistic target for most manufacturing companies. As the latest survey of the VDMA in cooperation with the Laboratory for Machine Tools and Production Engineering (WZL) and the FIR e. V. showed, 65.5% of the polled businesses affirm this statement [1]. In consideration of the fact that for instance material and information flows in production plants are getting more intersected and networked than ever before this is a huge challenge for the production manager. Furthermore customer demand tailored products in increasingly shortened throughput times. The production planning and control (PPC) is the major control lever for the production manager in order to face those challenges [2-4]. However, today’s production management has several weak spots, like planning based on defective or outdated feedback data and user-unfriendly IT-system operation. Furthermore the production manager often has to react to problems in the scheduled production run on the basis of gut feeling. In many cases there is no significant prediction of the consequences of performed actions available as a decision aid. Another problem of today’s production management is, that the person in charge often is not able to focus on the real problematic areas of production, because he receives too many interfering and irrelevant information. Therefore he needs a tool, that gives him decision aid and leads his focus to the right direction.

2. State of the art

2.1. Production planning and control

A key factor in costumer order processing is production planning and -control, which will be used interchangeably with production management in this paper. Its impact on the reputation and ability to stay competitive of a company is measured by parameters such as adherence to delivery dates is high. Though the results of the last survey about “Production
in Germany as a location for industry” from 2011 have shown deficits in PPC [5], there are still a lot of unsolved problems of the same kind in the new survey of 2013 [1]. The main problem within this survey is the use of non-exact parameters as well as the missing of relevant data (like revised customer data or the correct progress towards completion) that lead to mistakes in planning.

The concept of “the three layers model of value stream oriented production control” (see figure 1) developed by the Laboratory for Machine Tools and Production Engineering, integrates the logic of the production control by Lödding [6], [7]. This value stream oriented concept is the framework for the configuration of production control. In contrast to most other approaches which mainly consist of control strategies for job release and sequencing at machines, the concept of value stream oriented production control also includes order creation [2].

The basis of the model is the value stream that is created throughout the production process. It visualizes all production steps that have an equal production control configuration. The second layer is the production control that gives an overview of the production control and which data is needed from the third layer, the master and order data as well as the first layer, the value stream. As the highest level of the model the master and order data is the origin of all planning and control activities. The data that is created are work plans, bill of materials and the master production schedule. Because of the “interaction” of master data and production control or shop floor the third layer is able to close the gap of inconsistency between the master data and the production control and the shop floor that is “the origin of many problems in production control” [8]. To ensure that there are no inconsistencies within the master data a periodic feedback is implemented between the master and order data and production control.

Order creation, order release, sequencing and inventory control are very important factors to reach an optimized configuration [2]. Order creation is done within the second layer of the model and includes all necessary information about costumer orders, inventory and WIP. Order release is the transfer from the planning to the production phase and from this point on changes in the amount and finish date of the product are much more difficult to implement. Sequencing describes the process of scaling the jobs in front of the machine by using different kinds of strategies. Inventory control is an important logistics parameter that contains information about supply, storage and accessibility of items (raw material, in-process or semi-finished goods, finished goods) ensuring that there is no under- as well as oversupply. By effectively controlling inventory unnecessary tied up capital can be avoided [2], [9].

It is not possible to find a customized and optimized three layer model for a company if not all production control parameters are considered. That leads to the conclusion that the configuration of the production control immediately affects the logistic performance factors such as inventory, delivery accuracy, throughput time and capacity utilization as a whole.

Figure 1: The three layers model of production control [6]

2.2. Cyber-physical systems in production planning and control

According to Lee and Seshia, a cyber-physical system (CPS) is an “integration of computation with physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa.” Those systems have a wide range of application and can be used in applications such as traffic control and safety, energy conservation, avionics, critical infrastructure control or at a production facility [10], [11].

In this paper we want to limit the explanations of the CPS to a use in production facilities or more precisely to the production planning and control processes. Physical processes are monitored and controlled by sensors that are linked to a program through wireless or non-wireless internet connection and enable the production manager to react to real-time situations in a very short period of time and in an optimal way e.g. by using a handheld device. The manager gets an immediate feedback from the system.

The main aim of CPS in production is to create a large control loop over more than one or even all subsystems that enables the user to control a highly complex and large industrial production process without maintaining each subsystem. This is reached by a “heterogeneous network of sensors, actuators and processors” [12].

This high amount of data, sensors and the size of the network lead to the following main challenges in the implementation of those CPS in production:

- Real-time performance of today’s computer systems
- Reliability
- Nontransparent planning
- System solutions are often irreproducible for the user

Especially in production systems CPS have to be implemented in different fields of production such as logistics and production planning and control. Another challenge is to make this cyber-physical production system (CPPS) projectable and controllable for production manager. He has to be able to interact with the system in a very intuitive way. To reach this, an adequate interaction with the IT-systems that are used has to be established e.g. by using “management cockpits” which can be installed on a portable device. All of these challenges not only have to be solved in new factories
but also in already established production systems in an industrial environment. This makes it necessary to think of the integration of CPPS into the daily machine operation as well as into the production and organization process as a whole. It also affects the structure of today’s logistics in production. By using CPPS it will be more of a decentralized structure than a centralized [13], [14].

In order to solve the mentioned problems and challenges the architecture and real-time operation of the CPS have to be improved in the way of stabilizing connectivity and extend range of wireless sensors and to increase the capability of communication of each sensor and within the network. The sensors itself have to be integrated into a more reliable system that is able to sense, transmit and process all the heterogeneous data. The aim of current research and development is to find a way of providing such a system [12].

In a future prospect it shall be possible that a production system adapts itself very flexible to the current order situation without any impact from the outside user. The introduction of CPS including all the necessary sensor technology is seen as a seminal approach to eliminate the mentioned deficits in PPC. CPS enable real-time data transmission in the required quality and therefore can ensure a reliable PPC process.

3. Current deficits and deviated requirements

As described in the introduction of this paper, an efficient and well working production management is the major control lever for the production manager in order to face current challenges like increasing market dynamics and meeting the manifold customer demand. Constantly changing external and internal influences, which are hard to overlook in their entirety for the production planner, complicate his daily work and resilient decisions.

Production management in general, and also cyber-physical production management in detail can be split into two dimensions: a long-term one and a short-term dimension. In the following both dimensions will be described briefly.

The long-term dimension was derived from the question, what the root cause for systematic deviations between planned values and actual values could be. Potential dimensions for long-term actions would be e.g.:

- Sequencing
- Adherence to delivery dates
- Wrong target times
- Personnel and/or machine deficit
- Change in the work plan/work process

By improving shortcomings in these areas, the overall planning quality within the production planning and control system can be increased in the long-term. But advancements in these areas take time: Training of the personnel in methods like “single minute exchange of dies” to reduce setup-times and therefore reach the set target times is drawn-out. Changing the work plan because the planned sequential arrangement of the machines is not really reasonable in reality generally also takes a lot longer than a couple of days.

It is of utmost importance to resolve the long-term problems to realize an as stable as possible production process, but the production manager also needs a tool that helps him with urgent problems that come up during his routines. Therefore this paper will focus on the approach for short-term actions, which have an immediate effect in the upcoming few days. The following exemplary situation gives an impression about a typical problem in daily business life that affects the short-term dimension of production management:

The production manager of a medium-sized manufacturing company has no information until the following morning about how undertaken changes in the production control affected the production run of the late and night shift. In other words, he doesn’t know about the effects of his actions of production control on production in advance.

In many cases he has to trust his gut feeling about what action in what area he should perform to successfully equalize disturbances in production. It might work in most situations quite good, if he has a long history at the exemplary company, is well experienced in the field of production management and knows the production processes very well. But if he is comparatively new in a company and can’t rely on his gut feeling, a missing proper decision support can be a huge problem.

If he would have a model or a simulation tool, that would give him decision support by recommending short-term actions this would be a first step. If furthermore the tool would show him an estimation of the results of these short-term actions prior to their actual execution, the production manager could work more effectively in times of varied challenges. An advantage of decisions that are deduced from a simulation which takes the complete production area into account would be the following: the number of performed decisions, which might be locally reasonable but in the overall production system even counterproductive, because they interact with other decisions in an unexpected way, decreases.

The key requirements for an improved short-term production management in times of cyber-physical systems are listed below. The tool should give decision support about…

- …the areas of production, in which performing short-term actions seems justifiable
- …the quantity and types of possible short-term actions
- …the estimated impact of the various possible short-term actions on the production run in the upcoming week.

Three key questions can be derived from the characteristic requirements mentioned above, that will have to be answered on the way to an efficient short-term cyber-physical production management:

- …
• In what areas of production is the application of short-term actions reasonable? (see chapter 4.1)
• How can possible short-term actions of the production management be identified? (see chapter 4.2)
• How can the impact of those short-term actions be determined one week in advance? (see chapter 4.3)

In the following the presented approach of short-term cyber-physical production management will give answers to the raised questions above and how these answers can facilitate the daily work of the production manager.

4. Short-term cyber-physical production management

The roadmap to the approach of the short-term cyber-physical production management can be divided in three major steps, which are shown in the following figure 2:

Figure 2: Roadmap to short-term cyber-physical production management

4.1. Step 1: Identification of areas of production, in which the application of short-term actions is reasonable

In the previous chapter, potential dimensions for long-term actions already have been listed. Hence, for the approach of short-term cyber-physical production management this step has to be done for dimensions of short-term actions. The areas for short-term actions were identified through expert interviews with production controllers of medium-sized manufacturing companies and extensively discussed afterwards. The resulting dimensions of production that are basically affected by short-term actions are described in the following passage:

• Capacitive bottleneck
• Organizational bottleneck
• Work in process
• Adherence to delivery dates

There are two different types of bottlenecks that can be distinguished – on the one hand the capacitive bottleneck and on the other hand the organizational bottleneck:

• The capacitive bottleneck is a production area or a specific machine, where the scheduled production volume is greater than the availability in that area or of that machine.
• The organizational bottleneck is also a production area or a specific machine, where there is enough capacity of the machine for the scheduled production orders but where the production order is not being processed although there would be enough staff scheduled (but isn’t present at the machine).

An intelligent sensor, that is attached to the machines will steadily detect whether personnel is available at the machines or not. By combining this sensor data with the feedback data of the machines, the intelligent tool can determine whether an organizational bottleneck might exist at a machine.

Work in process (WIP) are all intermediate goods and materials of a manufacturing company that are waiting for subsequent processing. In general these items are kept in storages or they are waiting in buffer queues next to producing machines. Due to the fact that all work in process items are bound capital and therefore not available for investment and need costly storage space, the task for the production manager is to keep work in process items on a balanced level [15].

When the amount of job orders that are in the production is very high, the work in process is also very high. The machine utilization will be also quite high, because most machines will have enough orders to work on. When the amount of job orders on the other hand is very low, and work in process is also very low, the throughput times will be rather short. But there is the risk of bad machine utilization, because not all machines might have enough job orders waiting for processing. Accordingly there must be an optimal area of work in process, where the throughput times are still comparatively short and the machine utilization is comparatively high. Figure 3 displays the above mentioned areas of work in process:

Figure 3: Levels of work in progress

The different areas of too few, optimal or too much work in process will be calculated with the help of logistical characteristic curves. The difficulty is, that logistical characteristic curves like the ones developed by Nyhuis and H.-P. Wiendahl, that mathematically describe correlations between logistic targets, are only valid for one work system, e.g. one machine [15], [16]. Current state of research is that a
way has to be identified, how these characteristic curves can be transformed so that they are also valid for a network of several work systems, e.g. a complete production area.

As a last dimension for short-term actions, a bad adherence to delivery dates was identified. It can be caused by two factors:

- A production order is completed and handed over more than three days in advance of the planned and promised completion date.
- A production order is completed and handed over later than the planned and promised completion date.

After the identification of the areas of production, in which the application of short-term actions is reasonable, another question emerges: What can the production manager do, in order to improve the situation in the identified areas?

In the following, possible actions are stated, that can have a direct impact on the production run of the upcoming few days.

4.2. Step 2: Identification of possible short-term actions

The actions are listed below the dimension of production, on which they have an influence on. The actions were identified and collected during many projects of the Laboratory for Machine Tools and Production Engineering with manufacturing companies as well as reviewed and approved during expert workshops.

- Capacitive bottleneck
  - extra shift
  - substitution of the machine
  - outsourcing of the order
  - command overtime
  - minimize setup-times (adjust job order)
- Organizational bottleneck
  - multiple-machine operation
  - staff from another area
  - outsourcing of the order
  - command overtime
  - extra shift
- Work in process
  - Release more orders
  - Release fewer orders
- Adherence to delivery dates
  - extra shift
  - substitution of the machine
  - outsourcing of the order
  - command overtime
  - minimize setup-times (adjust job order)
  - change prioritization

In the following, the possible short-term actions for the production manager are described in more detail.

Ordering an extra shift or commanding overtime for the next few shifts and/or days will increase the offered capacity in the affected areas and therefore attenuate potential critical situations in the dimensions capacitive and organizational bottleneck as well as it helps increasing the adherence to delivery dates. Sourcing out critical job orders to external producers also helps easing up the situation in the three areas of production mentioned above.

Other actions, like the substitution of a machine for example affect the short-term dimensions capacitive bottleneck and the adherence to delivery dates. Due to the fact that the organizational bottleneck has per definition enough machine capacity, the substitution of a machine would not have any impact on this dimension of production. The default assumption of the tool is that one order is rescheduled from a machine with no free capacity to another machine that still has free capacity for that order. Therefore the overall capacity will increase about the amount of the order and the problem of the capacitive bottleneck gets resolved as well as the situation of the adherence to delivery dates will get better.

Minimizing setup times by sequencing the job orders in a specific area so that unnecessary setting-ups are omitted increases the productive runtime of the machines in that area and therefore the offered capacity. Consequently the capacitive bottleneck as well as the adherence to delivery dates will be improved.

By establishing multiple machine operation, one worker will operate more than a singular machine and therefore his personal capacity gets increased. This might help mitigating organizational bottlenecks, because the worker now observes multiple machines that prior to that action didn’t have enough monitoring by personnel.

Getting staff from another area obviously will increase the offered personnel capacity and therefore resolve potential critical situations in the area of organizational bottlenecks and raising the adherence to delivery dates. Like multiple machine operation this action doesn’t help mitigating capacitive bottlenecks, because the machine capacity is not affected.

As described in chapter 2.1, order release is one major adjusting lever of the production planning and control. By releasing more or fewer job orders for the upcoming days, the production manager can instantly affect the amount of work in progress in the production area. The aim of this action is to reach the area of the “optimal amount of work in process”, where throughput times of job orders are still comparatively short and machine utilization is still comparatively high (see figure 3)

Changing the prioritization of job orders, i.e. more or less rush jobs in a current or near future production run will have an impact on the adherence to delivery dates.

As can be seen from the multiple assignments of some actions to more than one dimension of production, these actions cannot be judged separately. They have dependencies between each other, which have to be taken into account, when the impact of them on the production run has to be determined by the simulation tool. For example the action “order overtime” affects the short-term dimensions capacitive and organizational bottleneck as well as the adherence to delivery dates. By ordering overtime, the offered capacity in
the specific area is increasing about the ordered amount of overtime and therefore the capacitive and organizational bottleneck are resolved. During that overtime also the amount of rush jobs can be minimized and therefore the adherence to delivery dates gets better.

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The influences of the actions on the dimensions of production are marked in the following figure 4 (in the shown example the effects of the exemplary action substitute a machine on the dimension capacitive bottleneck is forecasted for the week commencing April 22nd):

4.3. Step 3: Simulation-based forecasting

Now that both the area of production and the possible actions are identified, this information can be used for generating short-term decision aid for the production manager, by telling him where he should focus his attention in the next days and which actions might have the greatest impact on the production.

The forecasting of what action to execute and in what area of production to do this happens with the help of a simulation model. In order that this simulation model represents the respective real production as good as possible all available characteristic information like sensor or other feedback data is constantly used to adjust the simulation model. This model is the basis for the simulation runs. The outcome of these simulation runs can be applied on the real production and be a decision aid for the production manager.

The constant feedback data from all participants of a production, like machines or products will also be the input for the simulation of the production situation in the upcoming days. Current and historical planning data will be taken into account during the simulation run and steadily revise the forecasted results of the simulation run. With the help of high resolution cyber-physical sensor technology, like RFID sensors for identifying an object or laser sensors for spatial position finding of a job order or material, massive data amounts can be collected. The task for the short-term production management tool is now to preprocess all data and aggregate the results to the real important and relevant data, which the production manager needs in order to operate successfully. By the time a problematic area of production is identified, actions mitigating the problem have to be found. The reliability of the actions and their effectiveness will be tracked and as a controlled process variable being integrated in the simulation model and therefore enhance the generation of new forecasts.

It is of utmost importance that the simulation model includes the complete system, in other words that the whole production system is represented and not only some parts of it. Latter would lead to the problem of partial optimization and not an overall optimization. In practical terms, it would mean that suboptimal actions for the whole production system could occur in the last-mentioned case.

The actual simulation runs with the help of Plant Simulation by Siemens. The scheduled upcoming few days of the production run are implemented in a simulation model and potential critical areas of production are accentuated. Actions, that can mitigate the degree of issue in these areas are simulated and due to the simulated outcome recommended to the production manager. If for example ordering overtime for 2 hours is enough to improve a shortage situation in a specific area, the tool would recommend that action. The actions are ranked in descending order according to their predicted effectiveness and presented to the production manager on a clear user interface. If for example another action could mitigate the above mentioned shortage situation cheaper or faster, the tool would recommend the actions due to their ratio of input/output in descending order. At this point of time, more research has to be done in order to achieve a well functioning prediction of the effectiveness of the actions. The ultimate decision of what action to perform is still at the production manager.

5. Summary and Outlook

In this paper the roadmap to short-term cyber-physical production management was described. Cyber-physical new intelligent sensor technologies, big data processing and simulation are enablers for providing possible actions for achieving a stable production in the upcoming week and therefore meeting the customer agreed date.

The three-part approach to short-term cyber-physical production management was depicted in this paper:

In the first step, the identification of areas of production, in which the application of short-term actions is reasonable, four areas were identified: the capacitive and organizational bottleneck, the work in process and last but not least the adherence to delivery dates.

In the second step, possible short-term actions were developed and specified, like releasing fewer jobs orders to reduce work in process or substituting a machine to increase
the offered machine capacity and therefore mitigate a potential capacitive bottleneck.

In the end, the scheduled upcoming few days of the production run are implemented in a simulation model and potential critical areas of production are accentuated. Actions, that can mitigate the degree of issue in these areas are simulated and due to the simulated outcome recommended to the production manager. They are ranked in descending order according to their predicted effectiveness.

Upcoming steps in the research process are the detailed composition how the effectiveness of the actions can be forecasted reliably as well as practical tests of the tool at industrial partners. Furthermore, a way has to be identified, how the characteristic logistical curves can be transformed so that they are also valid for a network of several work systems, e.g. a complete production area in order to derive the area of optimal amount of WIP for a production system.

With the help of cyber-physical systems the activities of the production manager can aspire to a qualitatively higher level than ever before. Especially in high wage countries like Germany an effective and efficient short-term cyber-physical production management will be essential for differentiation against competitors and therefore market success.

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