Chapter 11
Proposal of a Smart Production Planning and Scheduling in the Industry 4.0 Era

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Abstract Production planning and control system (PPCS) proposes a hierarchical system in which decisions follow an (almost) unidirectional flow for coordination between the objectives, plans and activities of the strategic, tactical and operational levels. Information systems have played a fundamental role in the implementation of these systems in organizations. However, these systems also have drawbacks due to their rigidity in decision-making, where coordination between different levels (with frozen plans) is not always possible in a short term, and not so much, by the productive capacity itself. The Industry 4.0 paradigm promotes, among other things, autonomous decision-making, interoperability, agility, flexibility, efficiency and cost reduction. This paper proposes the adaptation of the instruments available in the tactic and operational scope of the PPC system so that they are able to take advantage of the real flexibility and current information in their environment to provide solutions, with and expert system, which are more adjusted to the reality of each moment.

Keywords Production planning and control system (PPCS) · Industry 4.0 · Expert systems

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11.1 Introduction

The production planning and control system (PPCS) is a traditional proposal, in which recognized authors [10, 24, 30], establish the decision framework in the production process of most current companies. The PPCS proposes a hierarchical system in which decisions follow an (almost) unidirectional flow for coordination between the objectives, plans and activities of the strategic, tactical and operational levels. Each level pursues its own goals, but always taking into account those of the higher level, on which they depend, and those of the lower level, which they restrict. This hierarchical vision of production planning breaks down decisions into subproblems, which somehow, in the context of an organizational hierarchy, links the highest level of decision with those of the lowest level in an effective way [2]. The development of integrated decision models dealing with all decisions simultaneously may seem attractive, but these models tend to be very large, computationally demanding and inappropriate because it would not respond to the management needs of each level of the organization [3].

Managing the interdependent relationships of these decentralized decision-making systems is complex and requires mechanisms capable of coordinating the different decisions of each level together with the exchanged information [20].

This paper addresses the role that new technologies can play in the PPC systems and specifically in the planning and scheduling processes. For this, the paper has been structured in the following sections: Sect. 11.2 deals with deficiencies in PPCS, Sect. 11.3 presents a proposal to improve the planning and scheduling processes, and finally, Sect. 11.4 presents the main conclusions.

11.2 Deficiencies in PPCS

The importance of the information system that supports the PPCS is shown from the first proposals. The contributions of [2, 5, 11, 16, 17, 19, 28, 29, 34], among others, highlight the role that the information system plays in PPCS. The evolution of these information systems from MRP to ERP systems [9, 12, 25] has placed the information system as a main element in the PPCS.

Despite the advantages of information systems for hierarchical production planning, they also have drawbacks due to their rigidity in decision-making. In many cases, the hierarchical planning system faces alterations in the production process, urgent orders or breakdowns that would force altering the plans.

An example of these alterations is found in the ceramic sector when, due to uncontrollable factors during the manufacturing process, quantities and products different from those planned are obtained, which would cause the replanning of deliveries, the promising quantities or the master plan of production [1], the need to consider rescheduling is also emphasized in the field of hybrid flow shop [15], and something similar occurs in the industries of food processing [33]. Thus, the difficulty of replanning in hierarchical systems means that on many occasions, it is not carried out, and consequently, that companies do not respond adequately to unexpected events. The own structure of the hierarchical planning system establishes complex coordination mechanisms between levels. Decisions made using input data produce frozen plans which are transmitted to inferior levels in the hierarchy to continue making decisions, and these decisions are difficult to back out when new input data arrives. Therefore, the chain of decisions and the information system that supports it makes these changes difficult to do.

Thus, the gap between the theory and practice of PPCS is closely related to the associated information system. How the task is carried out in practice can be distanced of the information system designed [6]. This problem is aggravated when the design of the information system does not adequately collect information about the elements that interact in the domain (reduced or ignored information) [22] and/or the operation of the process itself (the designed system does not meet the real needs) [12]. Some examples are information systems for PPC designed years ago that ignores new information currently available for the production system, such as alterations in the production process, urgent orders or breakdowns that would require new plans. This misalignment between what the business wants (or needs) versus what the information systems allow is addressed from the perspective of business engineering in [8].

The need to adapt toward increasingly competitive markets, new organizational structures and greater flexibility, forces companies to more agile decision-making. To face the current dynamism, it is necessary to provide the information systems for planning with sufficient flexibility to achieve the proposals established in the PPCS framework.

11.2.1 Digital Transformation in PPCS

Technologies that facilitate these processes of change in industrial companies are located under the concept of "Industry 4.0". This new paradigm in the industry promotes, among other things, autonomous decision-making, interoperability, agility, flexibility, efficiency and cost reduction [23]. The digital transformation applied to the processes involves incorporating 4.0 technologies to make them more efficient and flexible [18]. Chavarría-Barrientos et al. [7] also address the areas of change in the scope of S3 (sensing, smart and sustainable—sensitive, intelligent and sustainable), for products, processes or companies, among others. The S3 processes are proposed as a solution to the ever-changing environment of the current digital economy. Continuous monitoring and processing will be provided through the use of emerging technologies, that is, Internet of Things, cloud computing, big data, integrated systems.

The vertical integration of intelligent "production systems" and the acceleration of manufacturing are two of the characteristics of the proposals in Industry 4.0 that add value [13]. Similarly, Moisescu and Sacala [21] present the potential offered by "sensitive" business information systems compared to current ones in terms of adaptability to changes in the environment and where they highlight cyber-physical systems in the production area. Weichhart [31] presents the advantages of what they call S3-ES (sensing, smart and sustainable enterprise systems) where required changes in production (both with respect to the product and services) are quickly identified, the data collected by sensors can be quickly sent to different decision models, and model reengineering can be facilitated. Weichhart [32] indicates the possibility of changes in the decision models through agents that communicate with the models. Shrouf [27] presents it as "new planning methods for the industry" and also the improvement of the management of unexpected events, using 4.0 technologies. In the field of production planning, it is addressed in [4, 26], and in the field of production scheduling, it is addressed in [14]. However, many of these proposals are presented as expected benefits of the set of technologies for Industry 4.0 and only a few specify some part of the set of decisions.

11.2.2 Identification of Deficiencies in the Current PPCS

Thus, the review carried out allows us to identify a set of elements in the field of PPCS where to investigate improvements. The deficiencies identified are described in Table 11.1. The identification of these deficiencies allows working on a significant number of research lines to deal with one or more of these elements in one or more of the activities developed in the PPCS. In our case, we have focused on the planning and scheduling processes.

Table 11.1 Deficiencies in the current PPCSs

Nr.	Description
1	The decomposition of the decision process into subproblems facilitates having models approvable by the decision-maker; however, these models have a partial view of the problem
2	There are no precise assessment procedures to determine coherence between levels
3	The PPCS is a traditional and widely used proposal, so the new proposals face the inertia established in the traditional vision
4	Information systems for PPCS are complex and rigid, following the theoretical approach and leaving out practical reality
5	The decision-making cycles are shortened, which obliges the decision-makers to alter the proposals of the information systems in order to adjust more to that reality and improve the proposals
6	It is key to identify obsolete models. The decision models made by the model designer may not correspond to reality (changes in processes over time, misinformation of the model designer, …)
7	The PPC information system is not prepared to absorb and process the data available in the company thanks to 4.0 technologies
8	The S3 processes in the PPC field are an aspect that needs to be specified

11.3 Proposal to Improve the Planning and Scheduling Processes

The traditional PPCS presents a set of deficiencies, which has been condensed in the previous section. However, at present, there is a vast number of companies, in multiple sectors, managing its production following the PPCS proposal. A representation of the current decision-making systems under the PPCS can be seen in Fig. 11.1. Tactical decision-makers work in search of a planning whose fundamental results are the master production plan (MPP). The decision-makers create models with which they represent their planning policy (levels, inventory, availability dates, lot sizes, periods, horizons, etc.) and look for solutions with tools (optimal or sub-optimal), generating plans periodically. These models and their parameters change very little over time.

The information with which planners define the productive capacity is based on assumptions or calculations that may be unrepresentative of the reality of the plant, either because of the technical difficulty of carrying out the calculation or because of the absence of reliable data. In many cases, they are data based on experience and corrected on the basis of trial and error, which are fixed in the IT solutions remaining unchanged for a long period until a new revision is made. Once the tentative plans are obtained, they are analyzed to include non-modeled aspects (peculiarities of certain orders, etc.), correct proposals that do not conform to reality (unrealistic

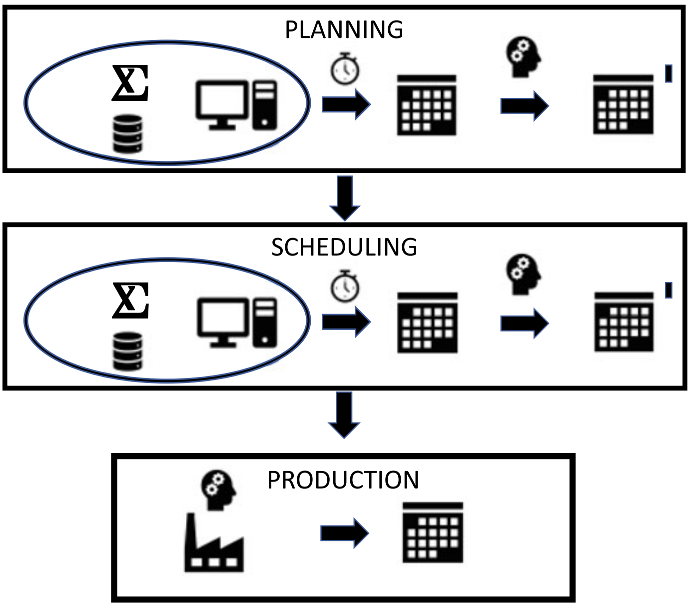

Fig. 11.1 Traditional plan and scheduling process

plant parameters) or simply improve the solution proposed by the algorithm. The final result is the final plan that is sent as input to the operational level.

Decision-makers of the operational level work in a similar way, they also have models to solve periodically where tentative production programs are obtained, and after an analysis, they will become definitive. These models consider the restrictions of the plant in much greater detail and as a consequence with much more complexity. In addition, they usually address a smaller time space (scheduling horizon). The operational level assumes as restrictions the needs of the tactical level and seeks for solutions oriented to sequencing and timing (assignment of orders to machines and/or workers, for example).

The engineering approach provided by the PPCS structure is still valid and provides the advantages indicated above, but we should try to cover the deficiencies presented in Table 11.1. We are in an industrial environment that is incorporating solutions based on the latest existing technology (Industry 4.0 proposals). These solutions deploy the world of Internet of Things (IoT) in the field of production and logistics, allowing companies to have data instantly on what happens in their production plants or in their transport.

A change of the traditional PPCS framework is proposed. Specifically, a system with greater integration and better use of information by defining a complementary layer between the tactical and operational level to obtain a smart production planning and scheduling. Figure 11.2 shows this proposal. This layer for the integration of the tactical-operative levels for improving the efficiency feeds on the plans and programs elaborated in the traditional PPCS. Also, the identification of the possible flexibility

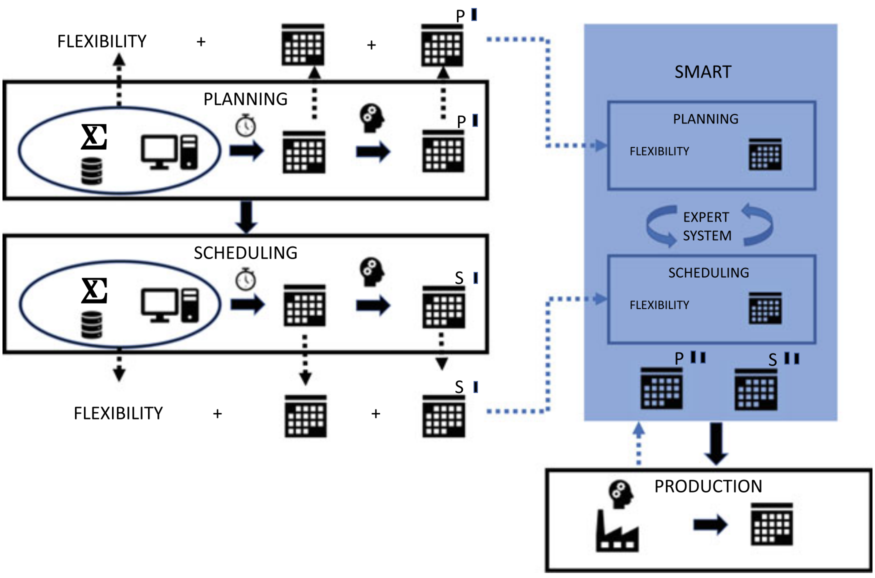

Fig. 11.2 Smart production planning and scheduling

in the system must be identified, as well as real data of the organization which has some kind of impact in plans and programs. These data may be being collected by the manufacturing execution system (MES), warehouse management software (SGA), enterprise resource planning (ERP) or the new systems that arise in the field of Industry 4.0.

The smart planning and scheduling proposed is based in the following hypothesis:

1. Current PPCS is a good starting point
   - The current system generates definitive plans and programs using a top-down approach in the decision-making. First, the plans have been generated and then the programs have been developed.
   - It is assumed that the plans and programs are the best possible for the current (mathematical) model and data used.
2. It is possible to identify real flexibility
   - Hard constraints (conditions that must always be respected) and soft restrictions (conditions that can be changed or have a margin) appear in the planning and scheduling models. The former may correspond to physical or contractual conditions of the plant, for example. The latter may be conditions related to internal policies that company want to use (on average).
   - Decision-makers known a set of alternatives associated with soft restrictions that can be used to adjust plans and programs according to the conditions of each moment. For example, reduce a lot, include more resources.
   - Real flexibility, in addition to constraints, may include the incorporation of new data or the modification of the initial objective.
3. It is possible to introduce flexibility in plans and programs
   - It is assumed that production plans and programs can be improved by considering alternatives thanks to the soft restrictions.

Thus, the smart planning and scheduling will take the set plan-program obtained by the (mathematical) model used in the PPCS; also, it will take the plan-program modified by decision-makers because the introduction of some improvements. Furthermore, the information about the flexibility and new information (in real time) about the situation of some business process will be used in the smart planning and scheduling.

An expert system will identify possible improvements and generate a set of alternative programs, some of which are feasible with respect to the received model and therefore valid, and others are feasible thanks to the flexibility included. Finally, the best alternative (program-plan) will be selected from those existing based on a selection protocol.

This proposal does not require a complex integration in the current information systems and is based on a basic data exchange, since the logic of the process is completely located in the expert system, so its implementation in companies would not be very expensive.

11.4 Conclusions

This paper proposes the adaptation of the instruments available in the tactic and operational scope of the PPC system so that they are able to take advantage of the real flexibility and current information in their environment to provide solutions that are more adjusted to the reality of each moment.

The PPCS and its associate information system are being used in organizations, and the introduction of the Industry 4.0 concept is providing an important range of proposals in this area. The proposal presented in this paper focuses on the validity of the results obtained by the PPCS system as a first approximation, the identification of the flexibility that can be contributed to plans and programs and finally the use of an expert system that offers alternatives improvement of initial plans and programs.

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