available online: https://doi.org/10.1016/j.mfglet.2017.12.005

Scheduling research contributions to Smart manufacturing

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Abstract

The incorporation of high technology to production systems is bringing the advent of *Industry 4.0.* One of the mainstays of Industry 4.0 is the application of Cyber-Physical Production Systems (CPPS). CPPSs will redefine decision-making processes in manufacturing environments, integrating traditionally disparate functionalities in a single system. One of the questions to be answered is how will the process of scheduling activities be redefined in this scenario. We examine the advances in the scheduling literature and analyze which aspects should be taken into account in future designs. Among them, we focus on topics as dynamic scheduling, distributed scheduling and inverse scheduling.

Keywords: Industry 4.0; Scheduling; Cyber-Physical Production Systems; Smart Manufacturing; Decision Making Process

1. Introduction

Tech experts and pundits alike have predicted a new industrial revolution for the next decade. The new phase, named Industry 4.0, will imply a big shift in the manufacturing paradigm, with the Internet of Things (IoT) and the Smart Factory concepts playing major roles. The economic impact of Industry 4.0 is supposed to be large: for instance, the German GDP is forecasted to increase in more than 250 billion euros up to 2025, when the transition to Industry 4.0 will have been completed [1]. In the

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meanwhile, many things still lack a clear shape or definition. In this sense, Hermann et al. [2], compiled all the practitioner and academic information on this issue and propose the following definition of Industry 4.0: "*Industry 4.0 is a collective term for technologies and concepts of value chain organization. Within the modular structured Smart Factories of Industry 4.0, Cyber-Physical Systems (CPS) monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the Internet of Things (IoT), CPSs communicate and cooperate with each other and humans in real time. Via the Internet of Services (IoS), both internal and cross organizational services are offered and utilized by participants of the value chain*."

This definition states clearly the foundations for Industry 4.0, being CPS cornerstones of the new manufacturing paradigm. CPSs are defined as processing technologies with high interconnection between physical assets and computational tools [3]. Big expectations have been laid on them and their potential advantages led the National Science Foundation of the USA (NSF) and the European Commission to fund research and development projects aimed to create new CPS technologies.

In turn, CPSs integrate more sophisticated computational capacities into the physical production system. This yields the more complex notion of Cyber-Physical Production Systems (CPPS) presented in [4], which extends the basic concept of CPS to production systems, embedding them in manufacturing environments. Here we intend to investigate how the classical process of scheduling operations is affected by this new paradigm. In order to do this, we take a classical standard, the structure of control for production systems ANSI/ISA 95 and its associated decision-making procedure. First, we will analyze the standard established by ISA and its relation to CPPSs, in order to develop the new scenario. Then, we establish some research lines in the area of scheduling that may significantly contribute to the development of Industry 4.0.

2. The structure of ISA 95

ANSI/ISA 95 establishes the basic standard of how to manage a production environment. This standard is based on the 5 levels of the "Purdue Enterprise Reference Architecture" (PERA), as shown in Figure 1. Level 0 is associated to the physical process of manufacturing; level 1 to the intelligent devices that measure and manipulate the physical process; level 2 represents the control and supervision of the underlying activities; level 3 involves the management of the operations. Finally, level 4 is associated to the business activities of the entire firm. This architecture represents, in a synthetic way, the different activities and functions of a production system. Besides, it establishes the way in which the different levels are communicated; in particular that in traditional productions settings, each level interacts only with its adjacent levels.

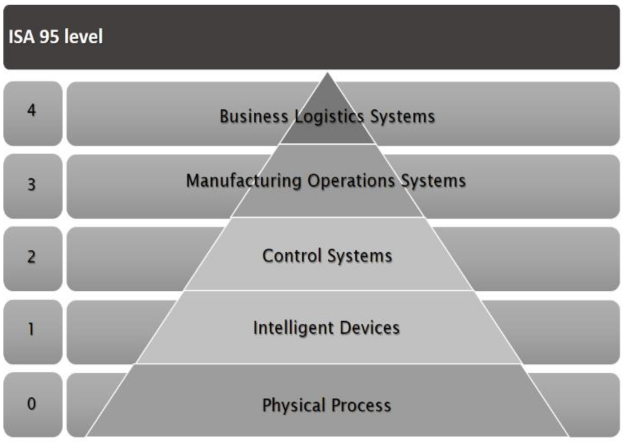

Figure 1: PERA (Purdue Enterprise Reference Architecture)

On the other hand, PERA defines a hierarchy in the decision-making process and the global control of the system. Level 4, the top one, establishes the goals and guidelines for the underlying levels, down to level 0, which is in charge of carrying out the plan.

2.1. *The structure with CPPSs*

CPPSs will change how decisions are made in the realm of industrial planning and control. To introduce our view on this topic, we show in Figure 2 the levels of ISA 95 that should be incorporated into CPPSs. This integration ensues from the capacities of CPPSs, which can enact the physical process (level 0), measure and handle the instruments reading the physical process (level 1), and implement control actions over its operations (level 2). Furthermore, given the computing power of CPPSs, they will also be able to plan, evaluate and manage the entire production process (level 3).

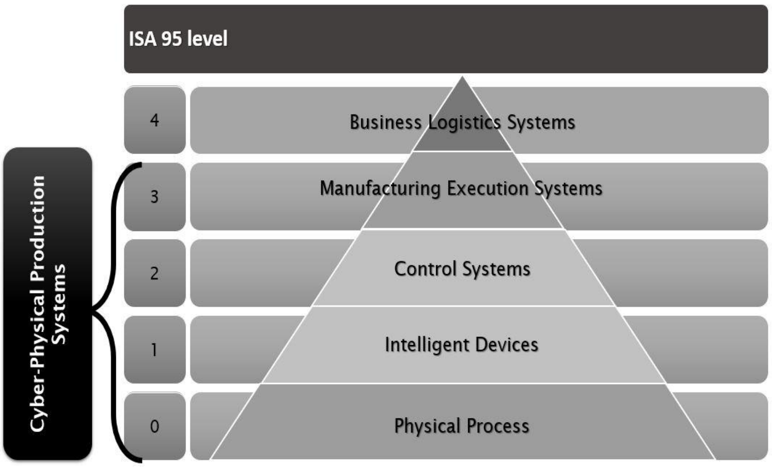

Figure 2: Levels of ISA95 integrated into CPPSs.

This integration of functionalities will yield direct benefits, as for instance increasing the flexibility of the production system in response to unexpected events; or the higher integration and transmission of information, given that a CPPS by itself can translate the data obtained at level 1 into the higher-level language used at level 3, bypassing the adjacency constraints inherent in PERA.

On the other hand, decision-making, focused on production planning, will be also impacted by the development of Industry 4.0. This will give rise to a new structure, which, while keeping PERA's levels, will be managed by two large systems: ERP (Enterprise Resource Planning) and the CPPS. Figure 3 shows this:

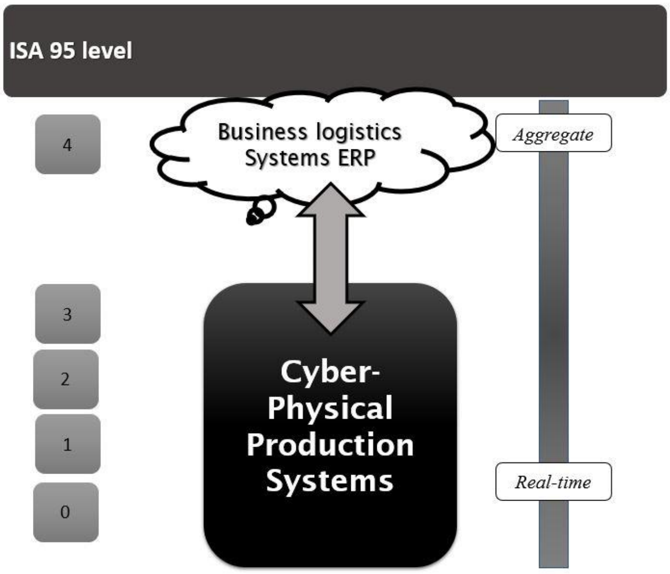

Figure 3. Distribution of ISA 95 levels between ERP and CPPS. The representation of time is drawn from the model of the Manufacturing Enterprise Solutions Association (MESA) International.

Figure 3 shows that the decisions about both the aggregate level and the goals to be pursued will be handled by the ERP systems (tuned for smart manufacturing environments). All other decisions will be automatically and systematically run by CPPSs, including the execution of the production plan in real time. In this structure, the CPPS can be seen as a set of autonomous elements collaborating to reach the goals set by the ERP system. This means, in particular, that current Manufacturing Execution Systems (MES), which take care of dispatching work orders and their scheduling in the shop floor, will be absorbed by CPPSs. This will yield information of better quality, useful for both making the decisions at this level and minimizing response times, increasing the flexibility of the entire system.

3. The role of scheduling

This structure, handled only by the ERP and CPPS systems, will redefine the way in which production will be planned. The traditional view, centralized and highly hierarchical, will make way for distributed features. This will, in turn, impact on the scheduling process, not only because decisions will be made collaboratively but also because the resources will be distributed [5]-[7], setting the stage for further developments. But the literature keeps treating the planning problem in a centralized and mostly static way. The MES is assumed to consider the entire set of distributed resources and dispatching orders according to that higher level vantage point. But the new paradigm requires the decentralization and collaboration of the different components, exchanging information acquired in real time. The scheduling community will face the challenge of developing new strategies and methods tailored for this new setting. In this sense, Zhang et al. [8], propose redefining the traditional methods and algorithms to the distributed framework. A particularly important contribution to these developments will arise from the incorporation of more complex structures, like those that arise in non-permutation scheduling of manufacturing cells [9][10].

A direct consequence of this new paradigm is the increase in the flexibility to respond to contingencies and unexpected events that may arise during the production process. This may include malfunctioning machines, the arrival of new orders or the change of priorities in the jobs to be carried out. This is the reason why dynamical scheduling will be an area that will have to be developed much further. Already existing proposals, reviewed by Ouelhadj et al. [11] will have to be extended. There exist different dynamic scheduling strategies, depending on the information taken into account and the intended degree of reactivity. In this sense, the notions of inverse optimization [12], applied to scheduling will yield new perspectives on this issue. In inverse scheduling the conditions for a schedule to keep being optimal are sought, including the range of processing times, delays, etc ([13], [14]).

4. Results: the Smart Manufacturing scheduling paradigm

In order to apply the developments in dynamical scheduling to Smart Manufacturing environments it is necessary to generate collaborative and distributed solution processes. The CPPSs must be able to modify schedules on the run, ensuring an increased flexibility. On the other hand, each component of a CPPS can act autonomously and experiment different events that can be seen as triggers of rescheduling. In this sense, the tools of inverse scheduling may help to establish effective tolerance degrees that allow discarding events that could trigger reschedules. In Figure 4 we depict the architecture that could implement these ideas. It is natural to speculate that via Big Data and Machine Learning, events could be classified in terms of what part and in which magnitude they affect the system, allowing establishing some of the criteria needed for inverse scheduling.

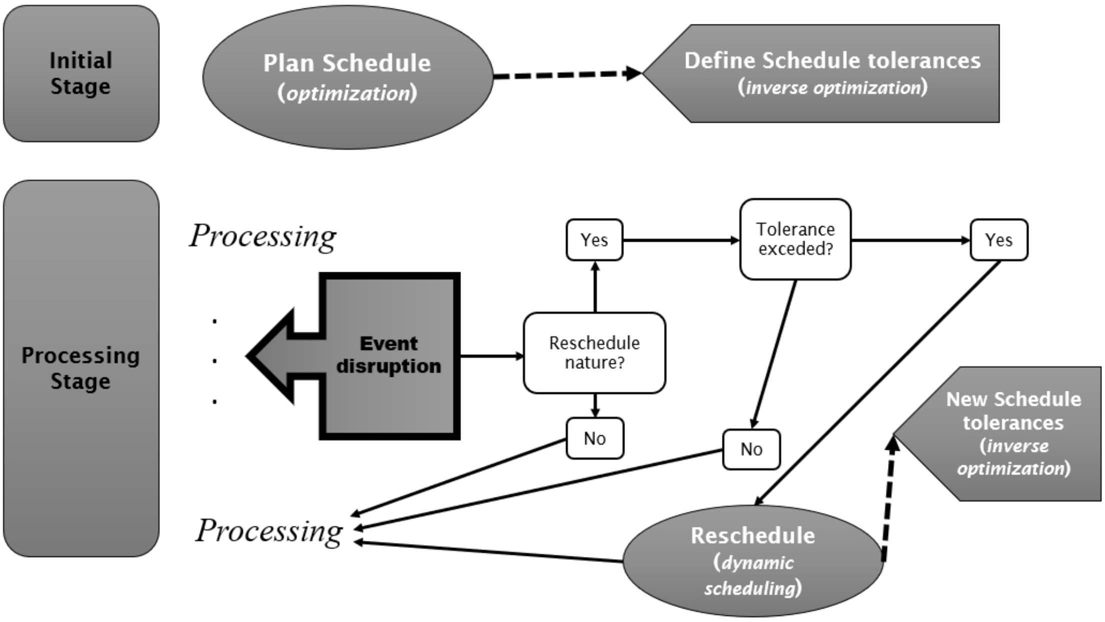

Figure 4. A new scheduling paradigm for Smart Manufacturing environment.

5. Conclusions

In this brief article we presented the scenario of decision-making in planning for Smart Manufacturing systems. We analyzed how the ERP and CPPS systems will interact. We also, stated some of the main scheduling problems that might arise in this new context and proposed some research topics oriented towards the solutions of those problems.

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