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ScienceDirect

Procedia CIRP 50 (2016) 442 – 447

www.elsevier.com/locate/procedia

26th CIRP Design Conference

Disruption Management for Resilient Processes in Cyber-Physical Production Systems

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Abstract

The increasing complexity and dynamics of cyber-physical production systems (CPPS) lead to a high vulnerability to disturbances during production processes. In the event of process disruptions, decisions must be made in short time in order to minimize the impact on production systems. In this paper, a simulation-based decision support for the disruption management process in a resilient cyber-physical production system is presented. Scenarios for disruption events and response strategies are modeled and simulated. The simulation results for each disruption event scenario are evaluated and the best possible strategy is recommended to the decision-maker including the expected impact on production processes.

Keywords: Cyber-physical production systems; Industrie 4.0; Disruption management; Decision support; Process simulation

1. Introduction

In the recent years, discrete manufacturing companies in high-wage countries are facing increasing challenges due to globalization, shorter product life cycles, and rapidly advancing technologies. Furthermore, the growing customer demands for individualized products and the high cost pressure also act as additional requirements. In order to overcome these challenges and maintain their competitiveness, manufacturing companies in high-wage countries are taking a new approach for developing new production systems with the focus on efficiency, individuality, and flexibility.

The research and development of such production systems based on cyber-physical systems is the subject of current research of the initiative Industrie 4.0 supported by the German Federal Government [1]. These highly flexible cyber-physical production systems enable the production of a high variety of products in small batches and similar costs to those of mass production. Due to its adaptivity, a cyber-physical production system is able to respond accordingly to the changes in market situation or turbulences in the production environment.

The increasing complexity and dynamics of processes in cyber-physical production systems, however, leads to a high vulnerability to disturbances during production processes. Moreover, due to the increasing application of digital technologies and connected systems in cyber-physical production systems, a failure in one subsystem can cause a disruption in another subsystem or, in the worst case, a complete standstill of the whole production process. In case of process disruptions or significant deviations from normal state, decisions must be made in short time in order to minimize the impact of failures and disturbances on production processes and guarantee a stable production result and delivery reliability. For this purpose, the reaction behavior of cyber-physical production systems in the event of process disruption has to be analyzed and included in the planning and design of cyber-physical production systems. Additionally, the integration of response strategies and decision logics in the production control is required.

In this paper, a simulation-based decision support system for supporting the disruption management process in cyber-physical production systems is presented. This paper introduces an approach for analyzing process disruptions and their impacts, and proposes the appropriate response strategies

doi:10.1016/j.procir.2016.04.144

that can be taken. The aim of the approach is to increase the resilience of processes in cyber-physical production systems by modeling the decision process and the communication between the decision support system and the simulation, as well as evaluating the response strategy of the system in the event of process disruptions in order to improve the reaction time and to minimize the impact of process disruptions on the entire production system.

2. State of the Art

2.1. Cyber-physical Production Systems

The foundation for modern manufacturing systems are cyber-physical systems. Cyber-physical systems are based on the two principles "*cyberizing the physical*" and "*physicalizing the cyber*" [2]. This means that every physical object has to be represented in the virtual world, and vice versa. Cyber-physical systems are embedded systems, which record data using sensors, analyze them using connected services, influence physical processes using actors, and interact with other systems using communication interfaces [3].

In the production domain, cyber-physical systems can be equipped in all production resources, such as manufacturing stations, automation devices, storage systems, and production facilities. In this way, they are able to autonomously exchange information, trigger actions, and monitor each other [4]. Therefore, cyber-physical systems are the key for the integration of different equipment on all levels of production [5]. The application of cyber-physical systems in the production environment leads to a cyber-physical production system (CPPS), in which every individual manufacturing object is the carrier of its individual manufacturing information [6]. Using this information and the equipped communication interfaces, these manufacturing objects can interact with each other and steer the production process by negotiating the optimum course of production and making autonomous decisions. The communication between each object in a cyber-physical production system can be executed either as an end-to-end communication or by using a central server [7]. The environment where smart products and smart production systems collaborate using internet technologies and context awareness, thus providing a manufacturing solution with an adaptive production process, is also referred to as a Smart Factory [8].

2.2. Failures, Disturbances, and Disruptions

During the course of production, failures and disturbances can take place and disrupt the production process or cause delay in the job execution. Failures and disturbances act as destabilizing factors in the production causing poor performance of the production system [9]. Due to the increasing demand for a short time to market, just-in-time manufacturing, and the trend to reduce inventory, a disturbance that occurs in one element of the system can have a considerable impact as the time to react before the disturbance effect is perceived is becoming shorter [10].

The effect of failures and disturbances can range from unsatisfied user demands, to insufficient resources, damaged infrastructures, and - in the most extreme cases - danger or harm to humans, machines or the environment [11]. In the production environment, disturbances can be categorized in planned and unplanned downtime, speed losses, and quality problems [9]. Due to the increasing use of communication technologies in a cyber-physical production system and the importance of information transparency, disturbances can also be caused by missing required manufacturing information or a failure of the communication interfaces [12].

In this paper, failures are defined as the nonfunctional state of a system element while disturbances are perceived as the deviation of the normal state of the process. Consequently, the terms failures and disturbances are summarized into the term disruptions, as both failures and disturbances cause the process to be disrupted. Following the definition in [13], a process disruption is defined in this paper as an unexpected temporary event caused by failures or disturbances during the execution of a manufacturing operation, where the deviation between the current and planned state is significantly large that the plan has to be modified substantially.

As process disruptions are unwanted and unplanned events that appear unexpectedly, their time of occurrence and duration can often not be predicted [10]. The lifecycle of process disruptions can be extended from the lifecycle of disturbance handling and is divided in four phases (Fig. 1). The detection phase signifies the time between the occurrence of the disrupting event from a normal operating state and the time the effect of the disrupting event is perceived. In the analysis phase, the cause of the disruptions is diagnosed and analyzed. The development phase describes the decision-making process that is necessary to develop the countermeasure to solve the problem induced by the disrupting event. In the last phase, the solution defined in the previous phase is implemented and the system should return to its normal operating state [14]. The phase before the effect of the disrupting event is perceived can also be referred as the latent phase and the later phases as the manifest phase, which lasts until the disappearance of the disruption [10].

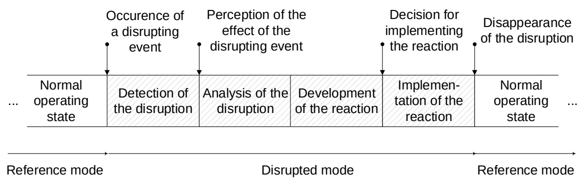

Fig. 1. Lifecycle of process disruption, modified after [14]

2.3. Decision Support System for Managing Process Disruptions

As process disruptions have a negative influence on the performance of a manufacturing system, reducing the effect of the disruption is the key to increased productivity and a better efficiency [9]. Therefore, the main focus of the disruption management is to reduce the overall time of the system in disturbed mode. This can be achieved by ensuring a fast and