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GENERATION OF ALTERNATIVES FOR MODEL PREDICTIVE CONTROL IN MANUFACTURING SYSTEMS

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Manufacturing systems are dynamic systems and subject to various internal and external disturbances, which often influence the expected behavior in an undesired way. Additionally, they have to deal with growing uncertainties, flexibility, and high cost pressure. These facts lead to changing circumstances for the decision making process. Decisions have to be made in higher frequency, which directly leads to a shorter time available for finding them. Therefore, a continuous process of decision making or controlling is required to make sure the aimed goals can be achieved. Additionally, the complexity of internal and external processes is rising. This situation impacts the amount of gained data obtainable from attached information systems. So the decision making process cannot be handled anymore by humans (Heilala et al. 2010) and decision makers are forced to use Decision Support Systems (DSS). In case of control of manufacturing systems, the situation is more challenging. Beside the higher frequency of times where decisions are needed, the controller has to evaluate several control alternatives and choose a solution optimal to the current situation. So control of manufacturing has to be performed in an automatically way.

In our research work we investigate methodologies and techniques to enable closed-loop control for manufacturing systems. A well-studied approach in automatic control engineering is model predictive control (MPC). MPC focuses on controllers which are using a model of the controlled system to estimate the impact of control alternatives. This information is used to determine a near optimal control input considering the current system state. Our current work focuses on enabling MPC for manufacturing systems.

To achieve this goal we had to deal with a basic problem. While MPC usually is based on analytic models (e.g. differential equation systems) manufacturing systems are hardly describable by this type of model. With this, we have no simple way to determine an optimal control input. In case of manufacturing systems discrete event simulation (DES) is the dominating model paradigm. DES is a well-accepted technique for planning, investigation and operation of manufacturing systems (VDI 3633-1). Basically DES could also be used to estimate the impact of control alternatives by prediction, which is required to enabling MPC. To match the requirements of MPC using DES we identified three major research tasks: the formal description of alternatives, the generation of complex scenarios based on combinations of these alternatives, and the generation and appropriate initialization of simulation models with the state of the real system.

The problem of keeping up-to-date simulation models could be achieved by forcing a closer integration of simulation techniques and manufacturing systems, like suggested by Fowler and Rose (2004). Several approaches focus on this basic idea, like the Online-Simulation approach (Davis 1999; Hanisch, Tolujew, and Schulze 2005), Simulation based Early Warning Systems (SEWS) (Hotz 2007), and Symbiotic Simulation Systems (Aydt et al. 2008). These approaches allow the simulation environment to observe the current system state and enable a faster generation of "what-if" analyses (WIA). In previous work we investigated an automated model generation and initialization approach (Bergmann, Stelzer, and Strassburger 2011) based on the core manufacturing simulation data information model (CMSD-IM). Based on this approach we are able to comply with the requirements of MPC for considering the current system state in simulation models.

Despite the potentials of model-driven control, observed applications in manufacturing are limited to the variation of parameters or scheduling. This is primarily caused by the lack of appropriate methods for describing and modeling of complex control options and decisions. To face this problem we focused on a methodology of how common decision and control alternatives (Table 1) in the operation of manufactur-

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ing systems can be formally described using the Core Manufacturing Simulation Data Information Model (CMSD-IM). The information model of CMSD-IM consists of several packages and classes, which helps to classify and structure domain specific knowledge about the investigated system. CMSD allows also to explicit define alternative resources, schedules or processes. We also investigated a methodology based on this information to extract explicit information. This could be done by processing process definitions and resources for finding equivalent operations, which are identified by its production input-output transformation. If an equivalent operation is found, its resource is regarded as alternative for other operations within its equivalence class.

Job Schedule		**Shift Schedule**		**Machine Utilization**	
customer-priorities	Job-priorities	Human Resource Flexibility	Overtimes	Partial Deliveries	Alternative Capacities
date-oriented priorities		Extra shifts		External Capacities/ Out-Sourcing	Express Deliveries

Table 1: Common alternatives in manufacturing control

Finally to enable MPC we had to investigate how to model complex scenarios based on the information of available control alternatives. This approach has to allow the selection of a subsets and enumeration of control alternatives. So the controller could dynamically build scenarios based on the current system state and iterate through the search space. The generated scenarios are afterwards evaluated in the simulation environment. Using a simple encoding, comparable to genetic encoding, is sufficient to fulfill this requirements.

With this approach we are able to enable MPC to control of manufacturing systems. Using the explicitly modeled manufacturing system and its control alternatives the controller can build complex scenarios. Using automated model generation and initialization a simulation model could be obtained and afterwards be evaluated. Due to the usage of CMSD-IM we are able to encapsulate a complete WIA. In combination with a problem solver (e.g. optimization algorithms) the controller can direct the generation of scenarios (WIA) and respond to the current state.

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