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Energy flow scheduling for parallel running batch processes

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Introduction

Nowadays, manufacturing systems are becoming complex due to the large number of processes they consist of. To be able to deal with this complexity, advanced control and scheduling techniques are used to ensure that the complete production process runs in a more efficient and reliable way than controlling and making decisions manually. At this moment, this is quite often done using model predictive controllers (MPC), which is still an important research topic in the field of systems and control. In this talk however, we focus on the definition and optimization of scheduling problems instead.

We focus on a specific type of manufacturing systems that consists of batch processes running in parallel. These batch processes can interact with each other, and therefore influence the production of different batches in these parallel processes. The interaction will be used as the decision variable in the scheduling problem as illustrated in Figure 1. These scheduling problems will be modeled using the so called max-plus approach, which can also be used for doing optimization afterwards.

We will show results for a case study for factories of the company Xella, where the production of calcium silicate stones is done in parallel batches, and where the steam flow between the processes will be the scheduling variable.

Max-plus systems

In scheduling problems, one tries to take decisions that influence the finishing times of (intermediate) products of each sub-process. Modeling the finishing times using the general framework of (linear) dynamical systems is not as easy as usual, hence another strategy should be taken to model these discrete event systems. Instead of using the regular operations as addition an multiplication, another algebra will be used where the basic operations are taking the maximum value of two elements, and adding them together. This is named the max-plus algebra. Without giving too much detail in this abstract, we can use this algebra to represent discrete event systems as linear max-plus systems

\[ \Sigma : \begin{cases} x[k+1] = A \odot x[k] \oplus B \otimes u[k], \\ y[k] = C \odot x[k], \end{cases} \]

where \( \odot \) and \( \otimes \) denote \( x \odot y = \max(x,y) \) and \( x \otimes y = x + y \). Here, \( x[k] \) is denoting time instances when a process is ready with the production of a batch \( k \). This is the mayor difference with normal (linear) dynamical systems. Earlier research has been shown that this kind of models can be used in optimization problems, hence can be applied to the problem we are dealing with.

To solve the scheduling problem of a factory where batches are produced in parallel, with interaction as decision variable, we have to make the following steps:

1. Modeling of the batch process: Each batch process that is running in parallel needs to be modeled, implying that the different stages for each batch of product are modeled using the max-plus algebra. Also the interaction moments with other parallel running processes need to be included in this model.

2. Defining interaction constraints: It is not possible to define interactions between arbitrary processes at any time or batch. This can, for example, be due to physical constraints in the factory. Therefore, we need to define these constraints, possibly also using the max-plus algebra, so that we can take them into account when solving the scheduling problem.

3. Defining the objective and start optimization: Now the model and the constraints are available, an objective function needs to be specified that needs to be minimized during optimization.

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