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MISPT: a user friendly MILP mixed-time based production planning tool

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Abstract

This paper presents an actual industrial application where a novel MILP based mixed-time formulation is implemented in a tailored software used in the daily production planning in the paper industry. The MISPT (Mixed Integer Strategic Planning Tool) is acting as an access point to various information systems at the factory. It uses information from the ERP (Enterprise Resource Planning) system and other information systems, and optimises the production planning. MISPT has a user friendly graphical user interface which helps the production planner to make daily decisions based on firm and precise facts instead of based on an "educated guess". The implemented novel MILP based mixed-time formulation is useful in the modelling of multi-stage multi-product production processes using intermediate storages with nonlinear optimal storage profiles, especially when ageing profiles in the storages are important. In the mixed-model, a continuous time representation is incorporated in a uniformed time grid, combining valuable features from both continuous and discrete time models.

Keywords: MILP, mixed-time, graphical user interface, industrial application, optimisation

1. Introduction

Globalisation has lead to harder competition and companies are forced to constantly strive for better efficiency in production, where the efficient use of energy and raw materials is of utmost importance. New techniques and applications give rise to new possibilities to strengthen the use of modelling and simulation in today's enterprise.

Scheduling plays a key role in process operations and may yield great improvements of production performance. Regardless of years of research and development, there still exists a large gap between industry's need for advanced decision making support and existing models.

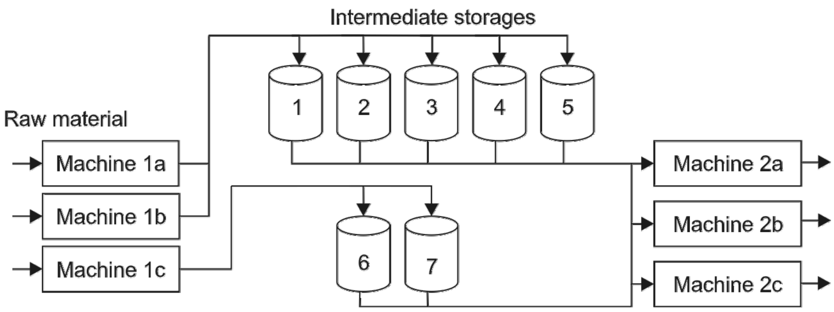


Figure 1. Process flow diagram of the factory facilities included in the problem formulation.

The novel MILP based mixed-time formulation, on which this tool is based, is presented in more detail in Westerlund et al. [1]. Maravelias [2] has earlier published a similar mixed-time representation for state-task network models. The MISPT software and an example, based on real data, is presented in more detail in the third chapter. The model includes 3 producing machines, 7 intermediate storages and 3 consuming machines. 5 different raw materials, and about 90 end-products, which are combinations of 1–5 raw materials, define the demands. Fig.1. presents a flow diagram of the actual process.

2. MILP based mixed-time formulation

The disadvantage of discrete-time models is that variable processing times can be handled only as discrete approximations, and that the number of intervals may be so large that the resulting model is too hard to solve, Maravelias et.al. [4]. This mixed-time model allows events, such as changeovers, to take place at any given time during each grid [2]. This procedure makes the mixed-time model significantly more flexible than a traditional discrete-time model [5].

Eq. (1) uses two continuous variables, $w_{i,k,t}$ and $p_{i,k,t}$, to determine the momentary production of each task, i, at each unit, k, during time sequence, t, where a traditional discrete time model typically uses one discrete variable and one continuous. The $w_{i,k,t}$ variable is determined by the binaries $y_{i,k,t}$ and $y_{i,k,t+1}$ as shown in Eq. (2). The variables $y_{i,k,t}$ and $y_{i,k,t+1}$ are only used to highlight if a task, i, starts or continues at unit k in the beginning of a time grid t. $y_{i,k,t}$ may be equal to zero, although the task i at unit k is performed during the time grid t, in case it will not start at the beginning of the grid. Thus, changeovers can take place within a time grid. Eq. (3) is used in the last grid N since no $y_{i,k,t+1}$ exists.

$$p_{i,k,t} \leq w_{i,k,t} \cdot p_{i,k,\max} \quad \forall i \in I, k \in K, t \in T \tag{1}$$

$$w_{i,k,t} \leq y_{i,k,t} + y_{i,k,t+1} \quad \forall i \in I, k \in K, t = \{1,2,3,...T-1\} \tag{2}$$

$$w_{i,k,N} \leq y_{i,k,t} \quad \forall i \in I, k \in K, t \in T \tag{3}$$

To make sure that no more than one task is performed at any unit at any time, except for the case when a changeover is taking place, Eq. (4) is used. To make sure that the maximum throughput level is not exceeded Eq. (5) is used.

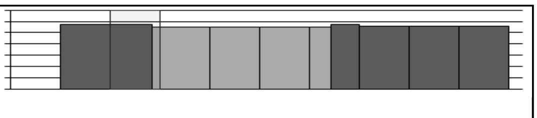
$$\sum_{i=1}^{I} y_{i,k,t} \leq 1 \quad \text{and} \quad \sum_{i=1}^{I} w_{i,k,t} \leq 1 \quad \forall k \in K, t \in T \tag{4–5}$$

To make sure that task i is performed, at least to a certain degree, at unit k during the time sequence t, if $y_{i,k,t}$ is equal to 1, Eq. (6) is used.

$$\sum_{i=1}^{I} w_{i,k,t} \geq \sum_{i=1}^{I} y_{i,k,t} \quad \forall k \in K, t \in T \tag{6}$$

The exact time for a changeover can be calculated using the $w_{i,k,t}$ variable according to Eq. (7) assuming constant production rates. $\Delta t_{i,k,t}$ represent the changeover time from the beginning of the time grid and Δt is the length of the specified discretisation grid.

$$\Delta t_{i,k,t} = \frac{w_{i,k,t}}{\sum_{i=1}^{I} w_{i,k,t}} \cdot \Delta t \quad \forall i \in I, k \in K, t \in T \tag{7}$$



$y_{A,k,t}$	1	1	0	0	0	0	1	1	1
$y_{B,k,t}$	0	0	1	1	1	1	0	0	0
$w_{A,k,t}$	1	0.83	0	0	0	0.58	1	1	1
$w_{B,k,t}$	0	0.17	1	1	1	0.42	0	0	0

Figure 2. Production schedule showing the use of the $y_{i,k,t}$ variable and the new continuous $w_{i,k,t}$ variables.

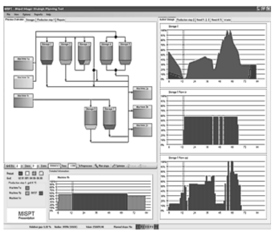


Figure 3. A screen shot of the actual software. [3]

3. The software

The customer was presented with a prototype of an application with similar features and then the new software was tailored according to the individual wishes. The base features and the design concepts were already made. The MISPT optimises the production plan based on the business inputs, which is the demand of products to be produced and the current storage levels, while taking into account global input variables, such as production capacity etc. The business output is the production schedule. The model adapts itself to the changing conditions of the dynamics of the real world. Changeovers at producing machines are not desired to take place every day and thanks to several intermediate storages it is possible, and desirable, to have changes only a few times a week. The demand may change more often and the optimisation must adapt itself to these changes. The valuable business output from this tool is the actual production schedule, including storage profiles, as seen in Fig. 3. The change in the demand can influence the robust production plan very quickly if the whole production strategy must be changed. These changes are very difficult for a single human being to recognise in time.

3.1. The architecture

MISPT is built as an access point to various parts and it combines these parts into a user friendly, intuitive application. The application consists of three major parts: the graphical user interface for input and visualisation, the mixed-time MILP model generator (ModGen) and the connection to, and the use of, the commercial mathematical problem solver ILOG CPLEX. The user imports the demands from external resources, which are not described here. These demands are set as hard constraints in the model. The current storage levels and the current production state are also input to the model.

3.2. User friendly interface

Much effort has been made on the usability of this tool. The end users have also taken part during the process in this matter. The goal was not to change the daily work of the end users, but to give them a tool which would produce precise facts to base their decisions on. The result from the optimisation is transformed mainly into charts and tables which give instant valuable information about the solution. The user can easily click on the interactive charts to compare different information. The core is of course the mathematical programming and the solution it provides, but without a user friendly interface the result would be impossible to utilise in practice.

3.3. Strategic planning

The model represents a real process, but the strategic planning option is taken into account for design and the user can easily configure most of the parameters that describe the process. The mathematical model can be configured by the user to fit different needs. For example, storage capacities and different production capacities can easily be modified through a dialog window. The user can even add a new machine to evaluate new production strategies. Some strict logical constraints for some parts of the process can also be replaced by more flexible ones to evaluate new strategic investments to improve the process. Some bottlenecks may not be visible in daily production, but through simulations of new possible improvements, without expensive costs, the overall production may be improved in the long run due to more flexible production strategies.

3.4. Planning of production stops

Machine failures are often unpredictable. Other serious situations may also affect not only the single, isolated part that is directly affected by the failure, but it may influence the whole production process. Using smart production planning, the situation can be solved conveniently. The MISPT offers methods to plan stops in advance in order to allocate adequate resources for service to prevent these failures. The user can optimise the problem once and evaluate where a stop would have the smallest impact on the production. The user then decides where the stop is held and re-optimises the problem. The stops are always at least one whole grid.

3.5. Ageing profiles

The model is suitable when the ageing profiles are important in the process. The products can not be stored in intermediate storages too long before the quality will be downgraded because of biological activities. Being aware of the problems in advance is very valuable for the production planner, who can react in time to prevent these situations.

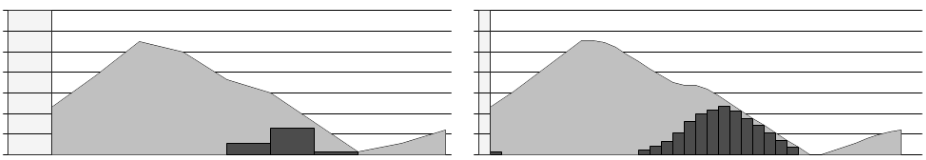


Figure 4. Stepwise linearisations of non-linear storage profiles. The lighter color is the current storage profile. The amount of “too old substance in storage” is clearly visible for the production planner (the darker bars). The two storage profiles represent the same situation, but with different length of the discretisation grids.

The time before the products in the storages are considered to be old during optimisation can be changed by the production planner according to e.g. climate changes and the time of the year. This information is translated into distinct constraints in the model based on these estimations. The optimisation will always try to minimise the amount of old substance in storage since these variables are penalised in the objective function.

3.6. The time grid and shift synchronisation

The user can choose the length of the grids and the horizon for the optimisation. The model adjusts the length of the first grid to synchronise the time line to the real shifts. The optimisation can start at any given time, the grids can be 2, 4, 8 and 24 h, and the horizon can be one day to two weeks. The left picture in Fig. 4 has 9 discrete time grids with a length of 8 h and the one to the right has 36 grids with a length of 2 h. The darker bars in Fig. 4 represent the amount of “too old” material in one of the intermediate storage. The current demand will automatically be transformed into discrete bounds for the model.

4. Conclusions

This industrial application has shown the practicability of MILP based production planning in industrial use. Overall, the MISPT is able to tackle very challenging industrial problems and has made a significant impact on the daily production planning efficiency. Furthermore, the MISPT software may also be used as an important platform in strategic investment decision making.
Continuous and careful use will likely give even more profitable results in the long run. The MISPT will minimise unscheduled downtime, material losses, and strategic investment costs, and maximise production and utilisation rate as well as end-product quality. It is worth noticing that however good the actual mathematical model is, the critical aspect for the end-user is usability.

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