Budapest University of Technology and Economics
Dep. on Manufacturing Science and Technology

Hungarian Academy of Sciences
Computer and Automation Res. Institute

Novel Methods for Decision Support in Production Planning and Control

New scientific results
of the
Ph.D. dissertation

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Summary

Taking the uncertain and complex environment into consideration, the selection of the most appropriate control decisions is a very difficult task. The results of the research presented in the Thesis focus on the decision support regarding the operational level of manufacturing systems. Special emphasis is given to the scheduling and rescheduling decisions, thus new rescheduling policies and schedule stability measures are introduced. Having the given production schedules as input, our main goal is to support decision makers in utilizing the scheduling system available at its best performance. Naturally, different scheduling algorithms and rescheduling strategies are compared and evaluated with the simulation-based methodology presented in the Dissertation.

One of the most important objectives of our research is related to the potential improvement of computer simulation, as applied to manufacturing systems. Among the current limits of simulation, existing tools fall short of offering effective integration into the process of production planning and control. In order to enhance the capabilities of simulation and make it more responsive to today's industrial needs, extended simulation is introduced and described in the Thesis, as a possible application approach of simulation on different hierarchical levels and in the various life-cycle phases of production systems, based on the requirements specified. Our proposed view of the combination of Digital Enterprise components and simulation, as well as the related information systems and interface connections are introduced. Theoretical solutions and results are validated by computational experiments, and through several (industrial) case studies, as well.

New scientific results

The results of the research presented in the Dissertation can be summarised in form of thesis's, as follows. New simulation modelling methods for the analysis of complex production systems are introduced in Thesis 1. Novel solutions developed for supporting production control decisions are treated in Thesis 2 and 3. A new, real-time, simulation-based active disturbance handling solution is described in Thesis 4.

Thesis 1:
Planning and analysis of complex productions systems based on extended simulation
The Thesis introduces and describes the *extended simulation* architecture*,* as a possible application approach of simulation modelling on the *different levels* and in various *life-cycle phases* of production systems, based on the *requirements* specified.

1.1. Extended simulation.
I proposed a vertical extension of the simulation on the hierarchical levels, by applying parallel (instead of separate, stand-alone simulation models), demand-driven, temporary simulation models, based on a common model structure (e.g. capacity planning then validating production schedules, Figure 1).
I developed novel methods aiming at the extended application of simulation over time. The core idea of the solution is to develop simulation structures appropriate for the different life-cycle phases, following the changes occurring over time in the complex production system under examination (e.g. factory planning, process planning, deployment of control systems, operation).

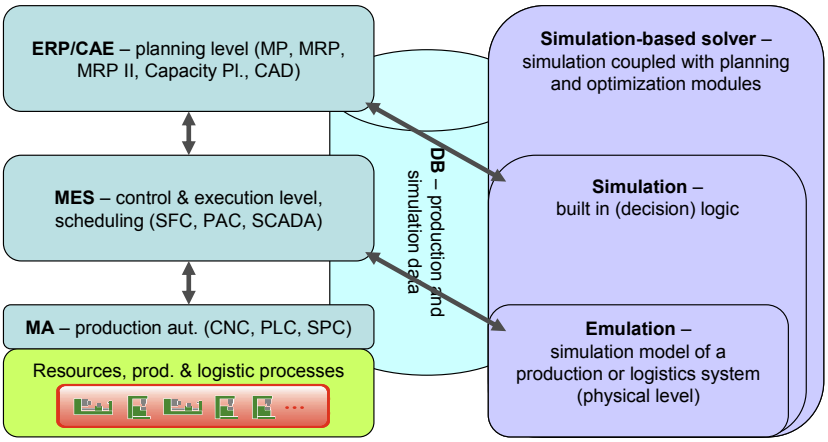

Figure 1: Proposed structure, possible functions and connections of productions simulation, given at the different levels of production information systems.

1.2. Development of a new, component based simulation modelling method.

I developed a new – component-based – simulation modelling method, based on data-base information, describing the production systems, as well as, based on predefined model elements. The simulation components are separate units, constituting different functions, and formalizing a certain structure for temporary simulation models, defined by the goal of the simulation study. The method is capable of effectively realizing the extended simulation structure, as proven by several case-studies.

1.3. Novel method for executing production schedules via simulation.

I developed and applied a novel execution model for simulation, which is capable of keeping the precedence constraints during the simulation analysis of assembly operations of resources and related production schedules.

The thesis is based on Chapter 4 of the Dissertation and on the publications [P10],[P6],[P7],[P8], [P11],[P1],[P6],[P9] and [P15].

Thesis 2:

Support for stability-oriented solution of dynamic rescheduling problems

The Thesis introduces a new schedule stability measure and the cost-based validation of the proposed solution.

2.1. Proposed new schedule stability measure.

I introduced a new, complex expression for measuring the stability of production schedules. The main advantage of the new measure is that during the schedule modification not only the rate but the actuality (relative to the execution) of the schedule modification is considered (1). Applied to multi-criterion analysis of rescheduling policies, and combined with efficiency measures, I proved the effectiveness of the proposed stability measure for dynamic rescheduling problems and a periodic rescheduling strategy.

$$\overline{INS} = \frac{1}{n_{pn}} \sum_{j \in B} \left[\frac{\left| t'_j - t_j \right|}{\min\left\{ t_j, t'_j \right\} - T} \right] \qquad (1)$$

where

B is the set of available jobs J that remained unprocessed in the initial schedule, and $|t_j' - t_j| > 0$ and $\min\{ t_j , t_j'\} - T > 0$,

n_{pn} is the number of the elements in B,
t_j is the predicted start time of job J_j in the current schedule,
t_j' is the predicted start time of job J_j in the successive schedule,
T is the current time, i.e., the point in time at which the rescheduling action is performed.

2.2. Cost-based validation of the proposed schedule stability measure.
I introduced a cost-model (four different types of costs) and a related simulation environment of a production system, in which the effect of the disturbances on resource constraints can be analysed. I confirmed that if the production schedules are modified (rescheduling), during the execution of the pre-calculated secondary schedules (e.g. transportation, material request) – calculated on the basis of the production schedule – additional costs occur. The time-based values of these costs occurred can be characterised by a decaying curve. On the results of the experiments, I stated that for the operations closer to the execution (actuality) in the secondary schedules, the average increase of the costs are always higher compared to the operations scheduled later in the time horizon.

The thesis is based on Chapter 5 of the Dissertation and on the publications [P3],[P12],[P13] [P14] and [P20]

Thesis 3:
Situation dependent control solutions for support and analysis of rescheduling decisions

3.1. Evaluation of hybrid rescheduling policies.
For the evaluation of hybrid rescheduling policies in a dynamic scheduling environment, I proposed a new method by which the pareto-optimal timing and rate of the schedule modification can be determined. I introduced a rescheduling threshold (2), based on the monitoring of the execution process of the operations. Based on simulation experiments, I verified that the efficiency measures do not significantly decrease during the control action is taken, moreover, the expected negative effect of the control action can be minimized, resulting in a higher overall schedule stability.

3.2. Control action curve.
I defined a control action curve, which determines for each point in time the required rescheduling threshold value (and thus the desired rescheduling policy as well) in the predictive-reactive scheduling environment considered. I verified the proposed solution by several simulation experiments, and it can be stated that depending on the situation occurred, the optimal timing and rate of the control action (rescheduling or schedule repair) can be calculated by applying the proper rescheduling threshold values.

$$\frac{1}{n}\sum_{j=1}^{n}\left|c_{j,sim}-c_{j,pre}\right|>\beta \quad , \qquad (2)$$

where
n is the number of the completed operations counted from the last rescheduling point,
cj,sim is the simulated end time of operation j,
cj,pre is the predicted end time of operation j.

The thesis is based on Chapter 5 of the Dissertation and on the publications [P2],[P3],[P5] and [P14].

Thesis 4:
New approaches for simulation supported active disturbance handling

4.1. Proactive and reactive operation modes of the simulation.
The main goal of the proposed proactive operation mode of the simulation is the on-line, anticipatory recognition of deviations from the planned schedule by running the simulation parallel to the plant activities (Figure 2). Thus, by using a look ahead function with short-term simulation runs (supposing of keeping the sequences as planned), support of situation recognition can be achieved.
I developed the reactive operation mode for the on-line analysis of the possible actions and decisions as well as minimization of the losses after a disturbance already occurred.

4.2. Proposed new disturbance handling structure.
I proved that based on the simulation approach and modelling method described in Thesis 1, an active disturbance handling structure can be formalized, which – applied on-line, as the part of the production control system – fosters the proactive/ reactive production control activities. I stated that the proposed system recognizes the changes and disturbances, related to schedule execution. The system identifies the different situations and, as an active reaction, provides evaluated decision alternatives to the decision maker.

The thesis is based on Chapter 6 of the Dissertation and on the publications [P4], [P16], [P17] [P18] and [P19].

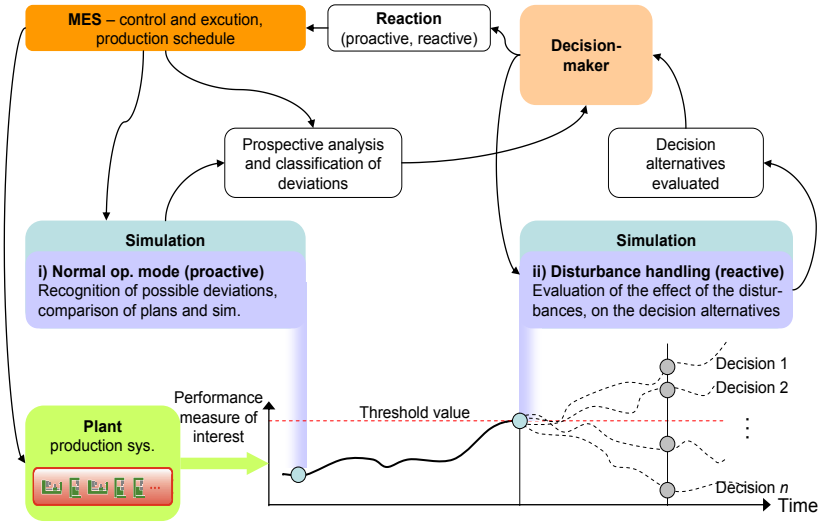

Figure 2: Plant-level active disturbance handling realized by using reactive/proactive operation modes for simulation

List of publications

Papers published in international journals

[P1] Kádár, B; Pfeiffer, A.; Monostori, L.: Building agent-based systems in a discrete-event simulation environment, Lecture Notes in Computer Science; 3690: Lecture Notes in Artificial Intelligence, Multi-Agent Systems and Applications IV, Springer, 2005, pp.: 595-599 (impact factor 0,402).

[P2] Pfeiffer, A.; Kádár, B; Monostori, L.: Stability-oriented evaluation of hybrid rescheduling methods in a job-shop with machine breakdowns, CIRP Journal of Manufacturing Systems, 2006, 35/6, pp.: 563-570.

[P3] Pfeiffer, A.; Kádár, B.; Monostori, L.: Stability-oriented evaluation of rescheduling strategies by using simulation, Computers in Industry, 2007, 58/7, pp.: 630-643,(impact factor 0,935).

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Papers published in the proceedings of international conferences

[P6] Pfeiffer, A.; Kádár, B.; Monostori, L.: Evaluating and improving production control systems by using emulation, Proc. of the 12th IASTED International Conference on Applied Simulation and Modelling, ASM 2003, 3-5 September, 2003, Marbella, Spain, pp.: 261-267.

[P7] Kovács, A.; Váncza, J.; Kádár, B.; Monostori, L.; Pfeiffer, A.: Real-life scheduling using constraint programming and simulation, 7th IFAC workshop on Intelligent Manufacturing Systems, ISM 2003, 6-8 April 2003, Budapest, Elsevier, pp.: 213-218.

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[P12] Pfeiffer, A.; Kádár, B.; Monostori, L.: Simulation support for rescheduling, Proc. of the 16th European Simulation Symposium and Exhibition, ESS2004, October 17-20, 2004, Budapest, Hungary, pp.: 41-46.

[P13] Pfeiffer, A.; Kádár, B,; Csáji, B.Cs.; Monostori, L.: Simulation supported analysis of a dynamic rescheduling system, in: Manufacturing, Modelling, Management and Control 2005, edited by Chryssolouris, G. and Mourtzis, D., 2005, Elsevier, pp.: 25-30, (also in Proc. of the IFAC Conference on Manufacturing, Modelling, Management and Control, October 21-22, 2004, Athens, Greece, pp.: 24-29.).

[P14] Pfeiffer, A.; Kádár, B; Monostori, L.: Stability-oriented evaluation of hybrid rescheduling methods in a job-shop with machine breakdowns, 39th CIRP International Seminar on Manufacturing Systems; The Morphology of Innovative Manuf. Systems, June 7-9, 2006, Ljubljana, Slovenia, pp.: 173-178.

[P15] Pfeiffer, A.; Kádár, B; Monostori, L.; Karnok D.: Simulation-based control strategy optimization by using genetic algorithm, Proc. Of the 8th International Conference on the Modern Information Technology in the Innovation Processes of Industrial Enterprises, MITIP 2006, September 11-12, 2006, Budapest, Hungary, pp.: 469-474.

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[P19] Kádár, B.; Pfeiffer, A.; Monostori, L.: Simulation-based monitoring and validation of production control decisions, IFAC Workshop on Manufacturing Modelling, Management and Control, November 14-16, Budapest, Hungary, pp.: 107-114.

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[P20] Pfeiffer A.: Újraütemezési döntések támogatása diszkrét eseményszimuláció alkalmazásával, Fiatal Műszakiak Tudományos Ülésszaka, 2005. március 18-19., Kolozsvár, Románia, pp.: 335-338.

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[P22] Czinege, I.; Ilie-Zudor, E.; Pfeiffer, A.: LOG4SMEs: Improving logistics performance of SMEs in the automotive sector, ERCIM News, J. of the European Consortium for Informatics and Math., No. 66, July 2006, pp.: 60-61.

Summary of the publications	
Sum of publications	22
Referred international journals	5*
International conference proceedings	17
SCI (db)**	4
Number of known independent references	9

*1 in print; ** cumulated impact factor: 2,611