Investigation of novel algorithms and their efficient implementations for resource distribution optimization of periodical industrial processes

Propositions of the doctoral (PhD) dissertation

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1 Objectives

Applying optimization it is motivating not only for the research itself, but also because it is beneficial financially, economically and environmentally. The reason for choosing it as the area of my research is that while one can achieve great results on a theoretical level, applying the right algorithms and methods can be of practical use, too and there is a need for that. During my years I had the oppurtunity to participate in a handful of projects. Collaborating with companies of the industry, such as Foxconn or SAGEM, allowed me to experience quite some real-life decision support problems. These tasks by their complex nature all needed some kind of computer asssisted decision making, even the ones given by smaller companies. Browsing the specialized literature looking for answers always ended up finding solutions that needed further development to some extent, or a different approach with a new model. I believe my results can extend the set of these already existing solutions. My thesis presents the problems I encountered along with their resolution and the results.

2 Methods

The results presented in the dissertation were based on the following:

- Problems that arise by their very nature require knowledge of the scheduling task specialized literature, such as mixed integer linear optimization, state space traversal solutions or S-graph methodology.
- The results were based on the process network synthesis methodology.

- Knowledge of Branch & Bound algorithms and their parallelization capabilities is essential for developing a resolving algorithm.

3 New scientific results

Proposition-like summary of the new scientific results of the dissertation:

1. **I have developed a general model for the multiperiodic description of process network synthesis and the implementation of the inter-periodic repositories.** [3, 6, 8, 9, 12, 13, 14]

   (a) I found that the multi-periodic models can be divided into variable and non-variable parts, which can be distinguished at the model level. On the basis of this, a multi-periodic model can be generated algorithmically by specifying the parameters of the variable parts.

   (b) Since most manufacturing processes have some storage capability, I extended the description of the multi-period model by introducing inter-period storage. I also developed a general model for implementing the storages.

   (c) I have given an algorithm on how to generate a multi-periodic model from a single-period model that contains storages.

   (d) Through special task types, I presented the possibilities of parameterizing the general multi-period model, such as production scheduling or energy distribution, where the method was applied in real case studies in the framework of industrial cooperation.

2. **I have created a model for the production line balancing problem based on the general scheduling previously implemented with PNS.** [1]

   (a) I provided a method to write "line balancing" as a scheduling problem.

   (b) I derived how to formulate the task of scheduling the production line balancing problem as a time-limited network synthesis problem, and then, after simplifying it as a quantity-limited network synthesis problem.

   (c) I tested the efficiency and effectiveness of the model and the software built into the decision support system based on real market data.

3. **I have created and optimized a parallel version of one of the solving algorithms of the P-graph.** [2, 4, 5, 7, 10, 11]

   (a) I worked out the parallelization of the P-graph algorithm RCABBs, which guarantees the N-best solutions.

   (b) I created a test base for testing PNS solvers, which is freely available.

   (c) With the test base, I determined which parameter settings are best for the created parallel algorithm.

   (d) I created task classes and determined the best parameter settings for each class separately. By means of these classifications, I made the parameter setting of the algorithm adaptive.

   (e) I experimentally verified the efficiency of the solver by comparing other solver solutions available for free.

4 Utilization of new scientific results

With the methods presented in the dissertation, I studied and optimized the multi-periodic systems and the production line balancing, which have been intensively researched recently. In the specialized literature there used to be less talk of multi-periodic scheduling before, and existing solutions at best could only reproduce the optimum and offered no alternatives. The models and algorithms created as a result of the research greatly expand the field of application of the P-graph methodology and are able to return with not only the best but also the N-best solutions.

In addition to theoretical results, the models and algorithms created have practical utility; tehy formed the basis of real-life software in collaboration with several industrial partners. An example is the production line balancing, where up to 25% efficiency improvement could be achieved, or storage and distribution of renewable energy in a microgrid system. It is not enough to build models, but it is important that the resolving algorithm should also be efficient. With parallelization and parameter optimization I successfully accelerated the existing algorithm, which is, at the same time, a solver found inside the P-graph Studio.

5 Publications on the topic of the dissertation

The following publications are available from the topics of the dissertation:

International journal articles

[1] Renewable energy storage and distribution scheduling for microgrids by exploiting recent developments in process network synthesis, Journal of Cleaner Production, Accepted: 2019, Expected publication date: 2020 (IF = 6,395)

[2] Anikó Bartos and Botond Bertók: Production line balancing by P-graphs, journal: Optimization and Engineering, 1-18. p, 2019. (IF = 1,824)

[3] Anikó Bartos and Botond Bertók: Parameter tuning for a cooperative parallel implementation of processnetwork synthesis algorithms, journal: Central European Journal of Operations Research, 1-22. p, 2018. (IF = 1,26)

[4] Anikó Bartos and Botond Bertók: Algorithmic process synthesis and optimisation for multiple time periods including waste treatment: Latest developments in P-graph Studio software, journal: Chemical Engineering Transactions, 70., 97-102. p, 2018.

Publications in international conference proceedings

[5] Anikó Bartos and Botond Bertók: Analysis of Search Strategies for Parallel Implementation of a Process-Network Synthesis Solver, proceeding: ASCONIKK 2014, 13. p, 2014.

[6] Anikó Bartos and Botond Bertók: Synchronization and Load Distribution Strategies for Parallel Implementations of P-graph Optimizer, proceeding: MACRo 2015, 303-313. p, 2015.

International conference presentations

[7] Anikó Bartos, Botond Bertók és Adrián Szlama: Optimal design of multi-period process networks including storages for renewable resources, conference: International Congress on Sustainability Science Engineering, Balatonfüred, Hungary, 2015.

[8] Anikó Bartos: Teaching Tools in the Logistics Tasks, conference: TIIKM'S 1st Annual International Conference on Education, Beijing, Chuna, 2015.

[9] Anikó Bartos and Botond Bertók: P-graph Framework: Computer Aided Model Generation and Solution for Supply Network Optimization Problems, conference: European Working Group on Location Analysis Meeting 2015., Budapest, Hungary, 2015.

[10] Éva König, Anikó Bartos and Botond Bertók: Free Software for the Education of Supply Chain Optimization, conference: VOCAL Optimization Conference: Advanced Algorithms 2016., Esztergom, Hungary, 2016.

[11] Anikó Bartos and Botond Bertók: Parameter tuning for a cooperative parallel implementation of process-network synthesis algorithms, proceeding: VOCAL Optimization Conference: Advanced Algorithms 2016, 96. p, 2016.

[12] Anikó Bartos and Botond Bertók: Energy Storage Capacity Optimization for Residential Areas, conference: 2nd eseia Conference on Smart and Green Transitions in Cities and Regions, Graz, Austria, 2016.

[13] Anikó Bartos and Botond Bertók: Estimation of the return of investment in new technologies regarding periodically changing demands, availability of resources, and

storages, conference: Chemical Engineering Days 2017, Veszprém, Hungary, 2017.

[14] Anikó Bartos and Botond Bertók: Software for Economical Evaluation of Utilizing Periodically Available Renewable Resources, conference: SPIL 2017 (Energy, water, emission, & waste in industry an cities), Brno, Czech Republic, 2017.