FlowOpt: A Set of Tools for Modeling, Optimizing, Analyzing, and Visualizing Production Workflows

Roman Barták[1*], Martin Cully[2], Milan Jaška[1], Ladislav Novák[1], Vladimír Rovenský[1], Con Sheahan[2], Tomáš Skalický[1], Dang Thanh-Tung[2]

[1] Charles University, Faculty of Mathematics and Physics, Malostranské nám. 2/25, Praha, Czech Republic

[2] ManOPT Systems Ltd., National Technology Park, Limerick, Ireland

[*] bartak@ktiml.mff.cuni.cz (contact e-mail)

Abstract

FlowOpt is a collection of modules built on top of enterprise performance optimization system MAK€ with the goal to bring unique modeling, optimizing, and visualizing capabilities for production workflows. FlowOpt is based on the concept of nested temporal network with alternatives used to formally describe alternative processes in workflows. The system supports visual design of nested workflows that can be connected with available resources in the enterprise. It then generates production schedules optimizing the on-time-in-full performance criterion. The obtained schedules can be analyzed to discover and "repair" inefficiencies of the enterprise. Finally, the schedules are visualized in the form of Gantt chart where the user can do any schedule modification interactively including selection of an alternative process or change of resource allocation.

Introduction

Though there exists a vast amount of research in the area of scheduling there is still a large gap between practical problems and research results especially in the area of production optimization for small and medium enterprises. This gap is partly due to missing modeling and visualization tools that would allow easy transformation of real-life problems to optimization models and the results back to customers (Barták et al. 2010) and partly due to large distance of academic algorithms from the existing problems.

FlowOpt project is a student's software development project at Charles University in Prague (Czech Republic) that is used to demonstrate the recent research results in the areas of modeling and optimizing production workflows. The project was realized in close co-operation with an industrial partner, ManOPT Systems from Limerick, Ireland. This project is a unique opportunity as usually researchers and final customers are too far from each other to communicate directly the needs on one side and the possibilities on the other side. In the project we wanted to demonstrate the recent research advancements in the areas of formal problem modeling and solving, namely using Nested Precedence Networks with Alternatives (Barták and Čepek 2008) to describe workflows, in real-life industrial setting. FlowOpt is a collection of four modules built on top of commercial system MAK€ being developed by ManOPT Systems as a tool for enterprise performance optimization. In particular, FlowOpt consists of the Workflow Editor, the Scheduler, the Gantt Viewer, and the Schedule Analyzer. These modules deal with creating, managing, scheduling, optimizing, and analyzing manufacturing processes for (small to medium) enterprises. The general purpose is to provide a streamlined feature rich environment where the user could do all of the following in a simple, efficient and user-friendly way:

- Specify how a particular product is manufactured (i.e. define a workflow describing the manufacturing of a single product).
- Enter a work order from a customer – customers request certain quantities of products that the factory can manufacture, together with a desired deadline.
- Generate a schedule for the order – a schedule should be a complete description of what elementary activities should be performed, in what exact times should they run and what resources should they use (machines or people). Executing such a schedule should result in efficient fulfilling of the work order.
- Display the generated schedule in the form of a Gantt chart and modify it interactively.
- Analyze the generated schedule for possible opportunities of improvement.

FlowOpt Architecture

FlowOpt modules are implemented as plug-in modules on top of MAK€ system which provides all integration capabilities. MAK€ contains a database where information being passed between the modules is stored, it also adds some modeling tools, namely for description of bill of materials, resources, time windows, and custom orders and it does some data integration, namely connection of abstract workflows with particular data regarding custom orders. MAK€ is a fully-featured product that already provided workflow editor, scheduler, and Gantt viewer. The FlowOpt modules are used as alternatives there with the focus on specific structure of workflows – nested precedence networks with alternatives.

FlowOpt Workflow Editor

Workflow Editor is the first module the user is exposed to. This module allows users to create and modify workflows. Workflow is a basically a set of activities connected via temporal constraints. We adopted the idea of nested precedence network with alternatives (Barták and Čepek 2008) to specify the workflow structure. Briefly speaking the initial workflow consists of the single task to achieve some goal and the user specifies how to decompose the task into sub-tasks until real operations/activities are obtained. Three types of decompositions are supported (Figure 1), either the task is decomposed into a sequence of sub-tasks which forms a *serial decomposition* or the task is decomposed into a set of sub-tasks that can run in parallel – a *parallel decomposition* – or finally, the task is decomposed into a set of alternative sub-tasks such that exactly one sub-task will be processed to realize the top task – an *alternative decomposition*. The module supports fully interactive construction of workflows with both top-down method of constructing workflows by the decomposition operations and the bottom-up method where existing workflows/tasks are joined in a similar style. When the structure of the workflow is defined the user can fill the most inner tasks by real activities and can define required resources for these activities. All these operations can be realized in drag-and-drop style.

In addition to core nested structure that is exploited during scheduling it is possible to specify additional relations between the activities going beyond the nested structure. In particular, the user can specify additional *precedence relations* between any pair of tasks which means that if both tasks are selected in the solution then the specified ordering must hold. The system also supports *synchronization constraints* so it is possible to describe that two tasks start or end at the same time or that one task must start exactly when another task finishes. Currently we do not support more general temporal constraints as the

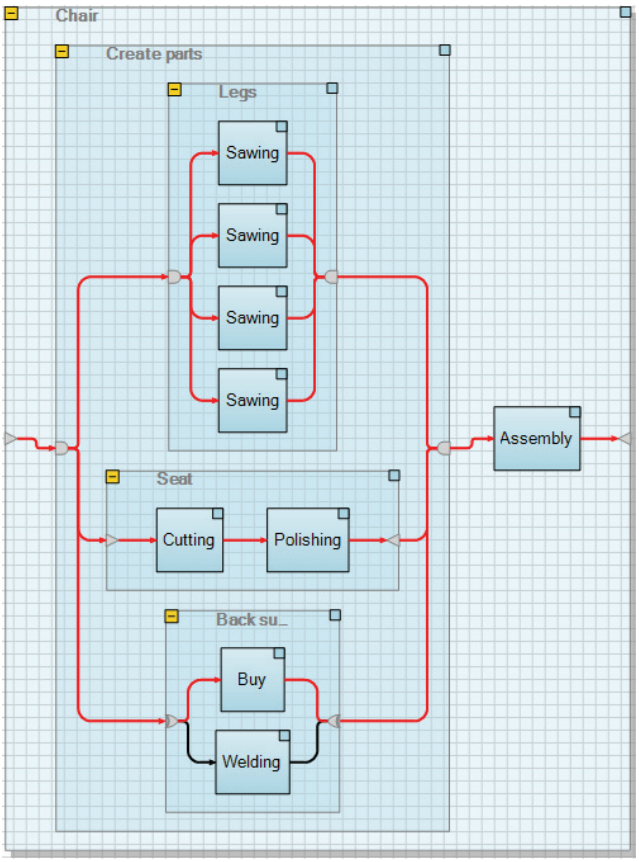

Figure 1: Visualization of nested workflow in FlowOpt Workflow Editor (from top to down there are parallel, serial, and alternative decompositions)

above constraints seem enough for most production workflows. We however support special *logical relations* between the tasks, namely implication, equivalence, and mutex relations which allow the users to describe some causal relations between the tasks going beyond the nested (hierarchical) structure. Basically, these logical relations restrict which activities can/must appear together in the schedule, for example, mutex relations mean that both tasks/activities cannot appear together in the schedule. These logical relations are novel in scheduling though they are frequently used in planning. We believe they will further simplify modeling of real-life problems, but further evaluation from customers is necessary.

FlowOpt Scheduler

When the workflow is described, it must be filled by particular data from custom demands. This integration is done by the MAK€ tool using the techniques presented in (Barták et al. 2010). A complete description of the scheduling problem that contains activities organized in a nested structure, specification of required resources, and description of deadlines is passed to the FlowOpt Scheduler. We use the idea of optional activities so the

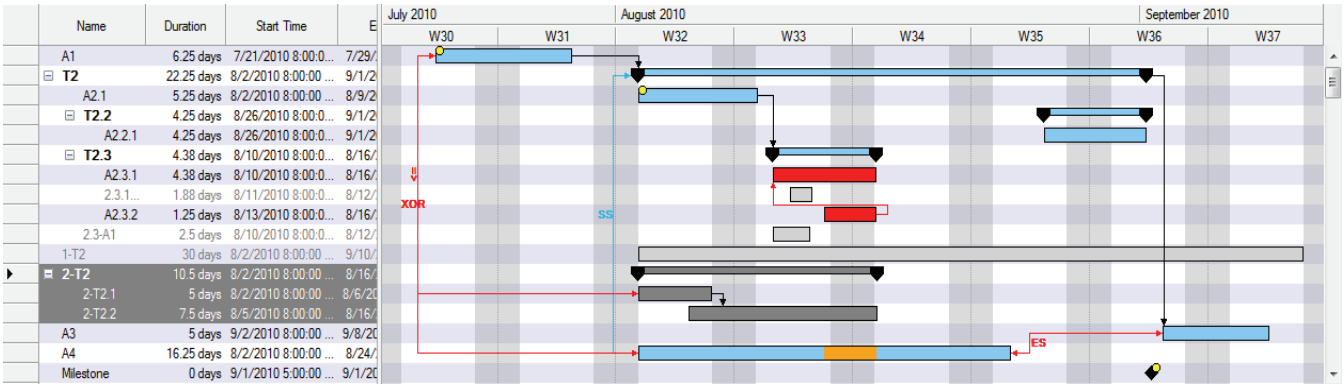

Figure 2: A task view in the FlowOpt Gantt Viewer. It displays the hierarchical structure of nested workflows, shows the additional constraints, and highlights the violated constraints.

system is doing some form of integrated planning and scheduling where activities used to satisfy the demands must be selected from the alternative processes and then allocated to time and resources. We use ILOG CP Optimizer to achieve this task as it already supports optional activities (Laborie and Rogerie 2008). To solve the scheduling problem we exploited only the existing constraints in CP Optimizer and its built-in search strategy, no special solving algorithm was developed. The result of scheduling is identification of selected activities that are allocated to precise time and required resources. The result from the Scheduler can go directly either to FlowOpt Analyzer or to FlowOpt Gantt Viewer.

FlowOpt Analyzer

FlowOpt Analyzer is probably the most innovative module in the FlowOpt system. It is responsible for analyzing an existing schedule and suggesting possible improvements of the enterprise such as buying a new machine. Note that these improvements are going beyond the analyzed schedule as they suggest how to change the enterprise rather than how to change the schedule only. The MAK€ system already includes schedule analyzer based on cumulative computing of certain key performance indicators such as utilization of resources or the number of late deliveries which are used to generate useful reports to the customers. The main difference from existing approaches in MAK€ is that the FlowOpt Analyzer does structural analysis of the schedule consisting of identifying critical activities (similarly to critical path detection) that cause delays of deliveries and finding a reason why these critical activities are itself delayed. Based on this analysis, the system automatically suggests possible modifications of the enterprise such as adding a new resource or exploiting overtime. These so called *improvement projects* are then evaluated by the scheduler simply by finding a new schedule after the modification and comparing quality of the new schedule with the quality of the original schedule. During the evaluation some inter-relationships between the improvement projects are also identified. All obtained information is then used in standard project portfolio optimization which will select a subset of most promising improvements.

FlowOpt Gantt Viewer

FlowOpt Gantt Viewer stands at the end of the modeling and solving process. As expected this module is responsible for visualizing schedules in the form of a Gantt chart. There are two major innovative ideas behind the Gantt Viewer. First, the module fully supports visualization of the nested structure of scheduled workflows including not-used alternatives. Second, the module allows interactive modification of schedules so the user can do fine tuning of the schedule. This interactive modification is similar to work (Barták and Skalický 2009) though automated schedule repair is not yet supported.

The Gantt Viewer allows both typical views of the schedule: a resource view that is useful to show occupation of individual resources (Figure 3) and task view showing the hierarchical structure of workflows together with time allocation (Figure 2). The task view provides visually more information as it shows not only the scheduled activities but also the non-selected alternatives and all these additional constraints between the activities as defined in the workflow editor. Moreover, the tool supports any modification of the schedule so users can change time allocation of tasks as well as resource allocation. This is realized by intuitive drag-and-drop operations. Users can also select alternative tasks if they are not happy with the choice of the automated scheduler. In such a case, the tool removes the previously selected alternative from the resources. Some other features are supported such as banning the resource so it cannot be used for activities or pinning the activity so it remains at the specified position. After manual modifications, the system highlights possible violated constraints though it does not repair them yet.

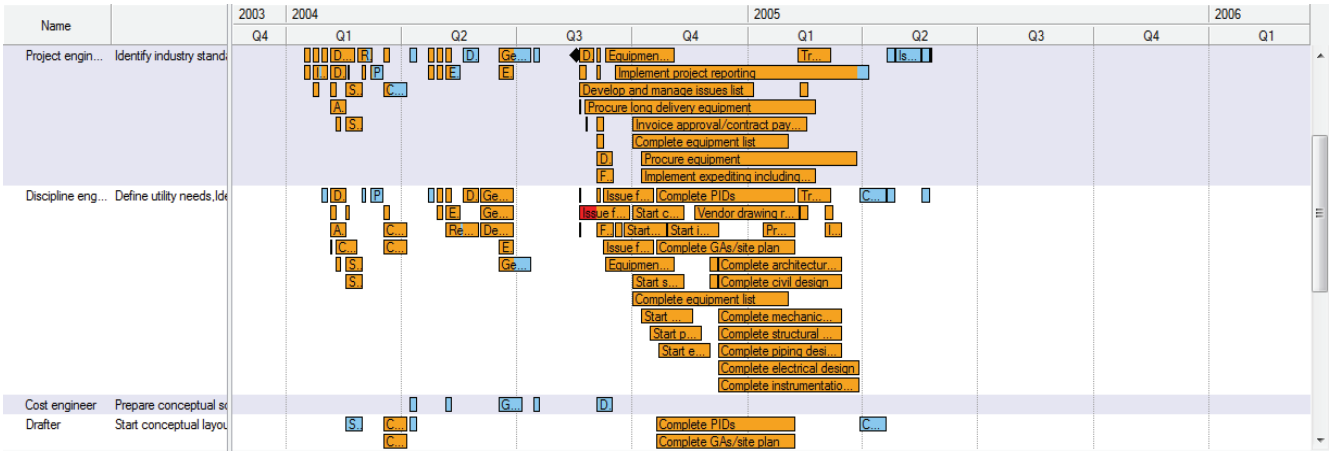

Figure 3: A resource view in the FlowOpt Gantt Viewer. It displays allocation of activities to individual resources.

Conclusions and Future Development

The MAK€ application has had a total of 15 years of use in five actual differing production facilities for example to schedule production of pistons or wooden doors. It uses a scheduling algorithm based on preferred routes specified by the users and some experiments were done with generic scheduling engine based on the constraint-based technology. The goal of the FlowOpt project is to test novel modeling techniques such as the nested structure of workflows and novel solving techniques such as using ILOG CP Optimizer. FlowOpt is not yet operational.

MAK€ with its FlowOpt extension is under continuous development driven by both customer requirements and novel research results. Three major extensions are planned for near future.

The Workflow Editor provides unique capabilities for hierarchical description of workflows with additional temporal and logical constraints. These additional constraints may introduce infeasibilities to the workflow, for example when the user wants to synchronize some activities, which may be impossible due to other temporal constraints. We are working on developing automated validation of workflows that can discover such infeasibilities and suggests the user how to remove them.

The Gantt Viewer on the other side of the modeling and solving process allows users to visualize and modify the obtained schedules. Any modification is allowed which may introduce conflicts to the schedule, for example some activity is manually allocated to a resource where the available capacity is exceeded. Currently, these conflicts such as violated constraints are highlighted to the user. The next version of the Gantt Viewer will support (semi-) automated schedule repair based on introducing additional changes to the schedule that will repair the conflicts while minimizing the number of changes and keeping the schedule quality (Barták and Skalický 2009).

The most novel part of FlowOpt is Schedule Analyzer that explores an existing schedule, detects possible inefficiencies, and suggests how to improve the quality of schedules by modifying the enterprise. We plan to extend this module to detect more inefficiencies and to suggest a wider spectrum of so called improvement projects. Also we assume a deeper integration with the Optimizer where the Analyzer can provide additional information for generating new schedules such as estimating where the bottlenecks appear.

Acknowledgements

The research is supported by the Czech Science Foundation under the contract P202/10/1188 and by EU Funding Scheme Research for the benefit of SMEs: FP7-SME-2007-1 under the project ValuePOLE (contract 222218).

References

Barták, R. and Čepek, O. 2008. Nested Precedence Networks with Alternatives: Recognition, Tractability, and Models. In D. Dochev, M. Pistore, P. Traverso (eds.): *Artificial Intelligence: Methodology, Systems, and Applications* (AIMSA 2008). LNAI 5253, Springer Verlag, pp. 235-246.

Barták, R., Little, J., Manzano, O., Sheahan, C. 2010. From Enterprise Models to Scheduling Models: Bridging the Gap. *Journal of Intelligent Manufacturing*, Volume 21, Number 1, pp. 121-132, Springer Verlag.

Barták, R. and Skalický, T. 2009. A local approach to automated correction of violated precedence and resource constraints in manually altered schedules. In *Proceedings of MISTA 2009: Fourth Multidisciplinary International Scheduling Conference: Theory and Applications*, Dublin, Ireland, pp. 507-517.

Laborie P. and Rogerie, J. 2008. Reasoning with Conditional Time-intervals. In *Proceedings of the Twenty-First International FLAIRS Conference*, AAAI Press, pp. 555-560.