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Design and implementation of a decision support system for complex scheduling of tests on prototypes

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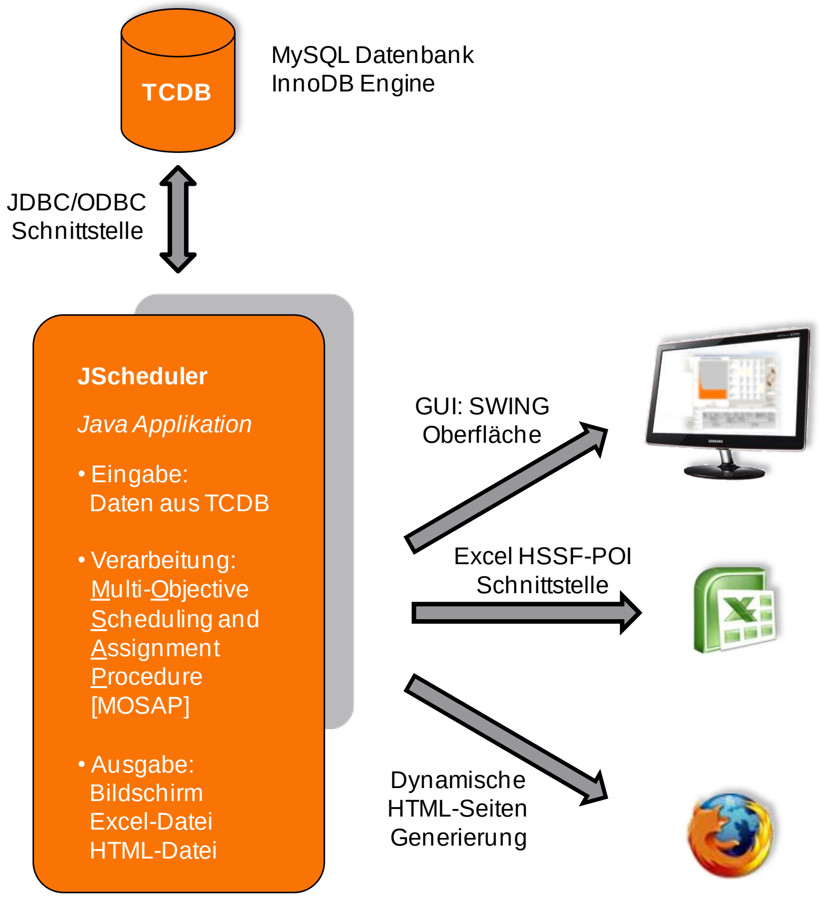

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Design and implementation of a decision support system for complex scheduling of tests on prototypes

Tim A. Rickenberg, Hans-Jörg von Mettenheim, Michael H. Breitner

Abstract Timing and allocation of resources for testing prototypes is a complex problem. Often hundreds of tests (hardware as well as software tests) have to be performed on a technical product before it can go into mass production. In this context, resources are limited: Next to a limited number of prototypes, a given number of testers with different sets of skills have to perform various tests with limited testing equipment within a certain period of time. It is necessary to assign tests to equipment and testers according to their availability. Tests have to be put in an appropriate order. For this complex task, decision support is needed in order to accelerate the manual planning process and the actual testing phase. Shortening the total test time can reduce costs and helps in achieving the start of production (SOP).
For scheduling tests on prototypes, we design, implement, and evaluate a decision support system (DSS). More precisely, our DSS enables the scheduling of tests on network components. With given sets of real world data of a leading manufacturer of data transmission systems, we suggest a formal description of the problem. We apply operations research (OR) methods to solve the underlying formal model and to generate optimized test sequences. Due to problem size and the number of variables and restrictions, we use heuristic methods in a multi-stage algorithm. The scheduling algorithm combines several heuristics in order to minimize the multi-criteria objective function. The graphical user interface (GUI) allows the user to interact with the DSS and to configure the optimization process. Also, the GUI can output scheduling results and timetables to screen and files in html or xls format.

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1 Introduction

Before a technical product can go into mass production, a significant amount of tests usually has to be performed on prototypes [4]. Individual components, the interaction of the individual components, and the system as a whole must be verified. This results in a variety of tests and test setups. The scheduling of tests on prototypes is a complex task [2] and needs decision support in order to generate feasible and efficient timetables. Tests have to be scheduled in an appropriate order to streamline the total test time and to reduce costs [4].

In this context, resources are limited: With a limited number of prototypes, a given number of testers have to perform numerous tests within a certain period of time. Test setups have to be arranged with limited testing equipment and tests have to be performed by testers according to their availability and skills. Next to the timing of the tests, equipment and testers have to be allocated to the tests.

We propose a decision support system (DSS) for the scheduling of tests on prototypes. More precisely, we design, implement, and evaluate a DSS called JScheduler which enables the scheduling of tests on network components. Starting with different sets of real world data of a leading manufacturer of data transmission systems, we develop a formal description of the problem (section 2). Based upon this, we apply operations research (OR) methods to solve the underlying formal model and to generate optimized test sequences. Therefore, we develop a multi-stage algorithm called MOSAP (section 3) which consists of heuristic methods and minimizes the multi-criteria objective function. The resulting DSS (section 4) supports planners with the scheduling of tests on network components: Raw data is imported from a database, processed by the scheduling algorithm, and scheduling results and timetables are output to screen and files. Finally, a conclusion is provided with a short summary and an outlook (section 5).

2 Problem Description

Based on sets of real world data, we present a formal model for the scheduling on prototypes. The formal model is particularly intended for complex scheduling of tests on data transmission and network prototypes. We argue that the model is largely generic and can be used for other problem domains (e.g. cell phone prototypes and other resource-constrained scheduling problems, see also [6]) as well. However, problem-specific adjustments or extensions can be necessary.

Since the formal description of our entire model is extensive, we limit the presentation to the key elements. Our more detailed formal model will follow within another academic outlet. The problem domain and the underlying formal model are characterized as follows:

A workset $w \in W$ includes all tests to verify a certain prototype. Test managers determine which tests are required and derive tests from predefined test cases. A test $t \in T$ is conducted by a tester $e \in E$. A prototype to be verified is called device under test (DUT). To perform a test, a test setup $s \in S$ is required. It consists of a DUT and several other components. A component $k \in K$ can be hardware (such as a measuring instrument, network component, module, etc.) or software (embedded or application software). All required components are set up according to a certain topology $a \in A$. By means of time slots τ with fixed length, a discrete-time representation is used.

To reduce the total test time t^{total}, tests with the same topology should be executed in one sequence. This allows the reuse of already built test setups. Thus, the preparation time t^{prep} which is needed to build a test setup can be saved. The time that a tester needs to perform a test is called handling time t^{hand} and the time that a test setup is occupied by a test (e.g. in long-term tests) is called holding time t^{hold}. Accordingly, the following equation applies: $t^{total} = t^{prep} + t^{hand} + t^{hold}$.

To perform a test, a tester needs a certain skill. The experience and skill set of an employee is represented by e^{skill}. With regard to the importance, tests can be prioritized: Important tests that may have an impact on the outcome of other tests or are very critical for the general test result, get a higher priority than other tests. Each test is assigned a priority $t^{priority} \in \{1, 2, 3\}$. Further, tests can be clustered manually. Experienced planners can define clusters of specific tests that are supposed be executed in a row by using the variable $t^{cluster} \in \{1, ..., n\}$.

Next to the exogenous variables stated above, endogenous variables are needed to perform the timing and assignment of testers, time slots, test setups and components to each other. The goal is to minimize the total test costs and time in order to start the mass production as soon as possible, to detect critical errors as soon as possible by prioritizing of test, and to ensure smooth and efficient testing. Accordingly, the objective cost function consists of multiple terms to determine an optimal sequence of tests:

$$\min.\left(\lambda \sum_{e\in E} f_e^{time} + (1-\lambda)\sum_{t\in T} f_t^{rearrange} + \alpha \sum_{t\in T} g_t^{skill} + \beta \sum_{t\in T} g_t^{prio} + \gamma \sum_{t\in T} g_t^{cluster}\right)$$

The first two terms of the multi-criteria objective function aim to minimize the costs of the total test time. The variable f_e^{time} represents the time-referenced costs of all Testers $e \in E$, and $f_t^{rearrange}$ represents the rearrangement costs of all Tests $t \in T$ in case a test setup has to be built. The next three terms are penalty costs: The variable g_t^{skill} is a skill penalty of all Tests $t \in T$ (in case a tester is not experienced with this type of tests), g_t^{prio} is a priority penalty of all Tests $t \in T$ (in case a test is performed even though there are untreated tests of higher priority), and $g_t^{cluster}$ is a clustering penalty of all Tests $t \in T$ (in case a test is not executed with the other test of the same cluster). The variables $\lambda, \alpha, \beta, \gamma$ are used to weight the terms stated above. Further, a normalization of the variables and terms should be performed.

By setting second order conditions and constraints, the feasibility of the optimization problem can be ensured. At the same point of time τ^*, each tester e, component k, and test setup s can only be assigned to (not more than) one test t. With respect to long-term tests, however, the tester is not tied to the test for the entire test time. As already mentioned, a detailed breakdown of equations and constraints will follow in a seperate paper.

3 Scheduling Algorithm

While the problem domain and the underlying formal model was described in the last section, an approach to solve the model numerically is outlined subsequently. To solve scheduling problems, operations research (OR) methods such as discrete and combinatorial optimization are applied, see [3]. We argue that the present problem is NP-hard, since the minimization of the makespan for two parallel identical machines is already NP-hard [2]. Small problem instances of NP-hard problems can be solved exactly by mixed integer programming (MIP) and branch and bound methods, while larger sized problems can be solved by heuristics. Due to the problem size, complexity and number of restrictions, we opted to use approximation algorithms and heuristics. Heuristic methods are able to find good solutions within a reasonable period of time, but do not guarantee to find the best solution [5].

To solve the scheduling problem and to generate optimized test sequences, we developed a multi-stage algorithm called MOSAP. The algorithm consists of heuristic methods and minimizes the multi-criteria objective function. The general procedure of the algorithm is presented in Fig. 1. Within the first step, data and variables are initialized. The initial values can be set by the user via the GUI or by an implemented hyper heuristic. The sequencing heuristics starts with the generation of a start vector. The initial starting point can be build randomly or calculated by a construction heuristic. A neighborhood search builds on the initial results and improves them. To search the solution space, two metaheuristics are implemented: greedy/grasp and simulated annealing [1, 7]. The matching heuristic performs the exact timing, allocation and solves conflicts. A timetable is created and time slots are transformed into explicit points of time. An optimized schedule is the output of the algorithm.

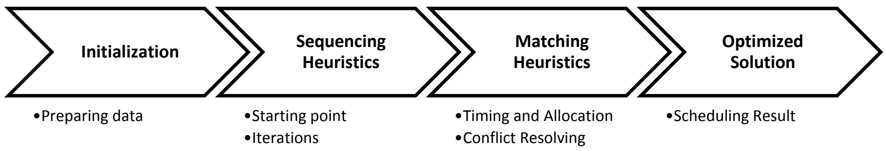

Fig. 1 Scheme of the Multi-Objective Scheduling and Assignment Procedure [MOSAP]

4 Decision Support System

As a proof-of-concept of our approach, we implemented a DSS called JScheduler [5]. The java-based prototype uses the MOSAP scheduling algorithm (section 2) to solve the underlying scheduling problem and model (section 3). It allows planners from the case company to efficiently plan tests on network components. Therefore, raw data is extracted from a database (Test Case DB). The data is prepared and processed within a pre-processing step. The actual scheduling of the tests is performed by the scheduling algorithm. Once the algorithm terminates, results can be output to screen or files (xls, html). The data flow of the system is shown in Fig. 2.

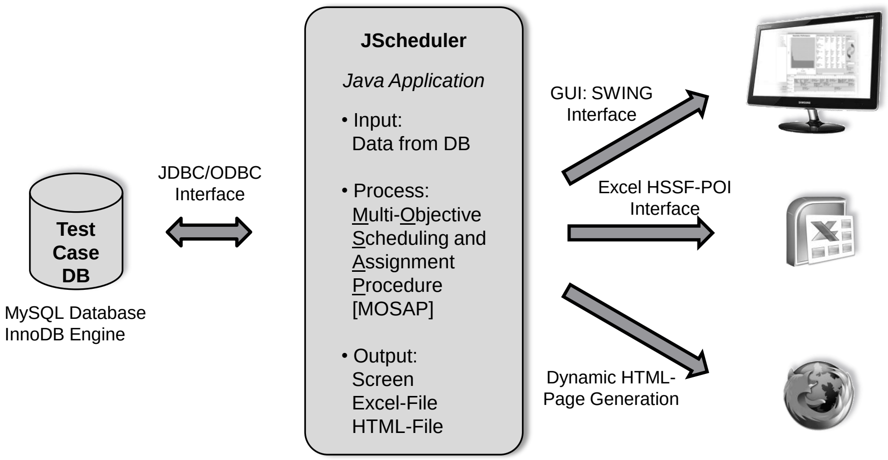

Fig. 2 Data flow and interfaces of the DSS JScheduler

A consistent GUI guides the user through the entire planning procedure: Starting with a screen to import data, another screen allows to set parameters and start the scheduling process, a third screen displays the scheduling results and the optimized timetable. The screen with the output of the results is shown in Fig. 3.

To evaluate the DSS, tests and benchmarks were performed with real-world data from the Test Case DB. An implemented hyper heuristic was used to set the optimization parameters automatically according to the actual problem and problem size. Due to the stochastic elements of the scheduling algorithm, multiple runs of the same instance do not necessarily bring the same result. Therefore, we present average values here: For 13 worksets with an average amount of 431 tests (ranging from 35 to 1130 tests), a possible total test time reduction of 25% (ranging from 20% to 33%) resulted. An average of 309 seconds (ranging from 17s to 1358s) was necessary for the optimization.

5 Conclusion and Outlook

For complex scheduling of tests on prototypes in general and for data transmission systems in particular, we contribute a formal description, a scheduling algorithm, and a prototype DSS. We briefly presented a formal model for the scheduling of prototypes; a more detailed presentation will follow. To solve the underlying model numerically, we suggested a multi-stage scheduling algorithm called MOSAP. In terms of a proof-of-concept, we introduced the DSS prototype JScheduler.

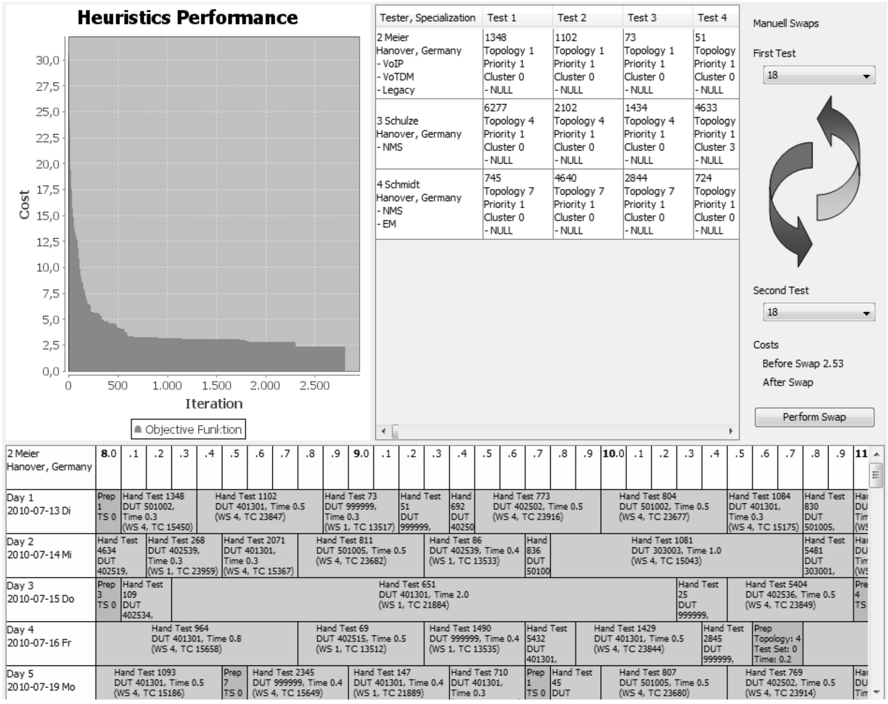

Fig. 3 Scheduling result generated from the DSS JScheduler

Based on our contributions and some identified limitations, implications for further research are drawn. We plan to design and implement a more sophisticated assignment procedure for our algorithm. Further, we intend to employ exact methods instead of heuristics to solve the problem exactly. A promising option are LP/MIP solvers such as IBM ILOG CPLEX which are able to find the best provable solution.

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