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Salewski, Frank

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Manuskripte aus den Instituten für Betriebswirtschaftslehre der Universität Kiel, No. 358

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*Suggested Citation:* Salewski, Frank (1994) : An integrative approach to audit-staff scheduling, Manuskripte aus den Instituten für Betriebswirtschaftslehre der Universität Kiel, No. 358, Universität Kiel, Institut für Betriebswirtschaftslehre, Kiel

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Nr. 358

# An Integrative Approach to Audit-Staff Scheduling

Salewski

December 1994

*Dr. Frank Salewski*, Institut für Betriebswirtschaftslehre, Christian-Albrechts-Universität zu Kiel, 24118 Kiel, FRG

**Abstract:** An empirical survey among the 200 biggest CPA firms in Germany has shown that the process of audit-staff scheduling requires a number of different decisions which differ markedly in terms of decision makers involved, length of the planning horizon and the planning periods, degree of aggregation of the audit engagements and tasks, respectively, problem to be solved, and decision objective.

Based upon these findings an hierarchical modeling framework with three levels is introduced. With respect to practical needs for flexible systems a concept for rescheduling is presented, too. Finally, the way how to integrate the single components, namely the three levels and the concept for rescheduling, into a whole system and how to use them is explained.

**Key Words:** Audit-staff scheduling, Hierarchical Model, Decision support system, Rescheduling, Regret-based biased random sampling

## I. Introduction

Since the scheduling of audit activities and manpower is one of the most cost-critical aspects of audit planning, decision support systems that reduce the time needed for planning and improve audit-staff scheduling can help to provide a better quality and more cost-effective service.

Traditional audit-staff scheduling models (Balachandran and Zoltners 1981, Chan and Dodin 1986, Dodin and Chan 1991, Drexl 1991) are single-level models which construct a direct assignment of auditors to tasks and periods. Due to the absence of extensive empirical investigations all these models have been assumed to be more or less gross simplifications of practical planning situations. This assumption led us to conduct a survey among the 200 biggest CPA firms in Germany (Salewski and Drexl 1993). Its results have shown that the process of audit-staff scheduling requires a number of different decisions which differ markedly in terms of decision makers involved, length of the planning horizon and the planning periods, degree of aggregation of the audit engagements and tasks, respectively, problem to be solved, and decision objective. Based upon these findings we formulated an hierarchical planning framework comprising three levels, viz. the medium-term, the medium-to-short-term, and the short-term audit-staff scheduling level. While many approaches to a lot of other problems of practical relevance claim at this point to have developed an in praxi usable framework, questions about how to handle information changes which may occur frequently are not answered. For this reason we introduce a concept for rescheduling, too, and explain how to integrate the single components, namely the three levels and the concept for rescheduling, into a whole system and how to use them.

The remainder of this paper is organized as follows. In section II we describe the new hierarchical modeling framework. In section III we discuss the main characteristics of the heuristic solution techniques used for solving the problems. Section IV is devoted to a concept for rescheduling, while section V explains the integration of the single components into a whole system. Finally, the results are summarized and future work is outlined in section VI.

## II. Hierarchical Modeling Framework

In this section the three levels of the hierarchical modeling framework are discussed. For each level the underlying assumptions and model structures are introduced in a non-formal (qualitative) way. (For a more detailed and technical description including the formulation of the problems in terms of binary optimization models cp. Salewski 1995.) Furthermore, the consistency relations between an upper and the corresponding lower level are presented.

*Medium-Term Planning*

The medium-term audit-staff scheduling problem (see also Salewski, Schirmer, and Drexl 1993) may be characterized by the following assumptions:

- A firm employs one or more *auditors,* which have to audit one or more *engagements* within a given *planning horizon* of normally 13, 26, or 52 weeks.
- Each engagement is made up of one or more *phases* (e.g. preliminary, intermediate, final audit).
- Between subsequent phases of an engagement, *minimum* and *maximum time-lags* may be given.
- Work on some phases may not commence before a specific *release time*, as well as it is to be completed by a certain *deadline*.
- The *capacity* of some *auditors* may be restricted in certain periods, e.g. due to holidays, or vacations.
- For some periods a client may want to confine the time during which the auditing takes place (*maximum duration of engagement processing*), e.g. due to client-specific events or stock-taking activities.
- Often an engagement could be audited by several alternative audit teams. Different team compositions (modes) will result in different *auditor processing times*. Usually some *modes* will be preferable to others: factors influencing the suitability of an auditor for a specific engagement are e.g. qualification level, industry experience, and familiarity with the clients business. The preferability of a mode as a whole may e.g. be linked to the total processing time needed. Hence, a *preference value* will be assigned to each mode.

The objective is to assign well-suited teams to the engagements (*mode* and *team assignment*, respectively) and to determine when the individual phases are to be executed (*phase scheduling*). The restrictions are:

- All engagements are scheduled completely.
- All phases of an engagement are processed by the same team of auditors.

- Precedence and temporal constraints are respected.
- Maximum durations of engagement processing are followed.
- Auditors' capacities are kept.

The medium-term planning which is mostly done by the upper management of an audit firm results in an assignment of auditors to engagements. It constructs a schedule of all phases, and determines the workload per auditor and week. If there exists with respect to the restrictions more than one feasible solution that one is taken which maximizes the overall engagement preference values.

*Medium-to-Short-Term Planning*

The medium-to-short-term audit-staff scheduling (see also Salewski, Bartsch, and Pesch 1993) is based upon the results of the medium-term level and provides a further specification of the weekly requirements. It may be characterized by the following assumptions (results from the medium-term level used in the following represent consistency relations which must be kept):

- The planning takes place for all *auditors* and for one period of the medium-term level. Therefore, the *planning horizon* usually has a duration of one week which is divided into periods of four hours length (half-shifts).
- As a result of the medium-term planning, the number of half-shifts where auditors are not available is specified. For this reason, the *capacity* of some *auditors* is restricted in a corresponding number of periods. During one period an auditor is allowed to work on at most one engagement.
- Again as an outcome of the medium-term planning, the number of *engagements* to be processed in the considered week and the number of half-shifts where the engagements cannot be worked on is given. Accordingly, the *processing* of some *engagements* is forbidden in a corresponding number of periods.
- The number of half-shifts (*jobs*) an auditor must *work* on a certain *engagement* is an outcome of the medium-term level.
- For some jobs of some engagements the auditors partly have to *work simultaneously* with some other auditors (e.g. for exchanging findings, reviewing).
- An auditor involved into two different engagements is required to have sufficient *travel time.*
- From an overtime scheduling of an auditor *period dependent costs* arise.

The objective is to determine when an auditor has to work on a certain engagement (*job scheduling*). The restrictions are:

- All engagements are scheduled completely.

- Auditors' capacities are kept.
- Auditors which partly have to work simultaneously on an engagement are scheduled at the same time.
- Restrictions of engagements' processing are followed.
- Travel times are respected.

The medium-to-short-term planning is regularly done by the engagement managers. Its outcome is a schedule for each auditor that covers - on the basis of periods of four hours - all engagements in which he is involved in the considered week. If there exists more than one feasible solution with respect to the restrictions that one is taken which minimizes the overall costs caused by overtime scheduling.

*Short-Term Planning*

The short-term audit-staff scheduling (see also Salewski, Böttcher, and Drexl 1993) is based upon the results of the medium-to-short-term level and yields a further specification of the engagements' weekly requirements. It may be characterized by the following assumptions (results from the medium-to-short-term level used in the following represent consistency relations which must be kept):

- The planning takes place for the *planning horizon* of the medium-to-short-term level, i.e. usually one week. In contrast, now only a certain engagement is considered, and the planning horizon is divided into periods of one hour length.
- As a result of the medium-to-short-term level it is specified which *auditors* are assigned to the engagement and when these *auditors* are *available* for processing the considered engagement.
- Each engagement is made up of one or more *groups of tasks* (e.g. audit of property, plant, and equipment), which in turn can be decomposed into one or more *tasks* (e.g. audit of increases, decreases, and depreciations of property, plant, and equipment). Each group of tasks must be processed by exactly one auditor.
- Often an audit task could be audited by several alternative auditors. Different auditor assignments will result in different *auditor processing times*: factors influencing the auditor processing time for a specific task are e.g. qualification level, and degree of difficulty of the audit task. On the other hand, some preassignments and / or nonassignments may be desirable (e.g. for the purpose of increasing experience, avoiding mismatching).
- Some tasks may not be executed before the completion of certain other tasks (*predecessors*).

The objective is to assign well-suited auditors to the groups of tasks (*auditor assignment*) and to determine when the individual tasks are to be executed (*task scheduling*). The restrictions are:

*Table 1: Characteristics of the hierarchical modeling framework*

| | medium-term level | medium-to-short-term level | short-term level |
|---|---|---|---|
| horizon | 3-12 month | 1 week | 1 week |
| lenght of periods | 1 week | 1 half-shift (= 4 hours) | 1 hour |
| consistency relations | | availability of auditors; number of half-shifts per auditor and engagement (jobs); restrictions concerning the engagements processing | periods of time in which auditors are assigned for processing the engagement |
| further level-specific requirements | | jobs to be done simultaneously by some auditors; travel times | tasks |
| scheduling objects | all engagements; all auditors | all engagements scheduled in the week considered; all auditors | one engagement with all tasks to be processed in the week considered; auditors assigned to engagement |
| problem | assignment of teams of auditors to engagements; phase scheduling | for each auditor scheduling of the half-shifts (jobs) to be worked on engagements | assignment of auditors to groups of tasks; task scheduling |
| objective | maximization of overall engagement preferences | minimization of period dependent (overtime) costs | minimization of auditors work over- and underload |
| decision maker | upper management | all engagement managers | engagement manager |

- All groups of tasks are scheduled completely.
- All tasks of a group of tasks are processed by the same auditor.
- Precedence and temporal constraints are respected.
- Auditors' capacities are kept.

The short-term planning which is done by the responsable engagement manager results in an assignment of auditors to groups of tasks and constructs a schedule of all tasks. If there exists more than one feasible with respect to the restrictions solution that one is taken which minimizes the overall work over- and underload of the auditors involved.

*Evaluation*

The hierarchical framework (cp. Hax and Meal 1975) for audit-staff scheduling which has been introduced is highly reflecting practical requirements because it is mainly based upon an empirical survey. Its basic characteristics are summarized in table 1. The consistency of the framework is documented by its hierarchical structure: each level has its own objectives, the outcome of an upper level is used as input for a lower level. By the way, this guarantees each decision maker to have views of the problems appropriate for himself and which are consistent to all other schedules. The advantages are obvious: in contrary to the other approaches mentioned above, in a situation where the upper management is interested in a whole-year schedule one does not need any detailed informations about any specific audit task but only about an engagement as a whole.

## III. Methods

This section outlines solution approaches which have been developed specifically for each of the levels. (For a more detailed and technical description cp. Salewski 1995.) Three reasons led to this development. (The following paragraphs of this section are quoted essentially from Salewski, Schirmer, and Drexl 1994.)

First, standard methods of integer programming seem to lend themselves to solving the models. However, even for modestly sized problems the model formulations translate into very large integer programs which in turn results in prohibitive running times. In fact, the NP-completeness and NP-hardness of the models with respect to feasibility and optimality, respectively, allows to conjecture that - except for the most simple cases - *no* exact scheduling algorithms will generally produce feasible or optimal solutions in a reasonable amount of time.

Second, apart from exact methods, a multitude of deterministic heuristics for approximately solving scheduling problems have been proposed (Alvarez-Valdés and Tamarit 1989a and 1989b, Boctor 1990, Davis and Patterson 1975, Kolisch 1995, Kurtulus and Davis 1982, Kurtulus and Narula 1985, Russell 1986, Talbot 1982, Ulusoy and Özdamar 1989). They all use priority values to resolve conflicts between jobs competing for the allocation of scarce resources (e.g. auditors). Unfortunately, since heuristics calculate priorities from only *some* of the parameters of a problem, they are not guaranteed to find an optimal schedule. In fact, heuristics may - especially in the presence of scarce resources - not even be able to find a feasible schedule (cp. Drexl and Grünewald 1993). Furthermore, deterministic heuristics yield *only one solution* for an instance, even if applied several times. Considering that this solution may be arbitrarily bad or even infeasible, determinism seems to be a major deficiency for heuristic methods.

Third, randomized methods try to overcome the shortcoming of determinism by performing the selection process randomly, but according to probabilities which are proportional to priority

values. In this way, in each scheduling step every phase, job and task, respectively, *may* be chosen, though those sharing higher priorities will have a higher probability of being selected. Due to their nondeterminism, repeated application of randomized heuristics will produce a *set of solutions* rather than one sole solution. Usually some of these solutions will be better than the one found with the deterministic version of the same method (cf. Cooper 1976). Moreover, no tie-breaking rules need to be specified for randomized methods: since they operate randomly ties cannot occur. However, even if the methods developed are borrowing from some of the ideas incorporated in the randomized scheduling method *STOCOM* (Drexl and Grünewald 1993), common heuristic scheduling methods cannot be utilized directly since these would not take the special structures of the models into account.

The algorithms may be characterized as regret-based biased random sampling parallel methods. For the medium-term and the short-term planning in a first stage the assignment of teams of auditors to engagements and of auditors to groups of tasks, respectively, according to priority rules takes place. Then, a schedule is built - for each of the three levels - by proceeding chronologically over all periods of the planning horizon. In each period the set of eligible phases, jobs, and tasks, respectively, is determined. From this set one is scheduled according to priority rules for starting execution in the actual period. This process of augmenting partial schedules is repeated as long as no restrictions are violated. Then the next period is considered etc., until eventually the planning horizon is reached. The resulting schedule is feasible if all phases, jobs, and tasks, respectively, are scheduled, and infeasible otherwise.

To ensure a systematic and consistent generation of test instances, for each of the parameters of the problem levels a domain and a discrete distribution function on the domain were defined from which parameter instantiations were generated randomly. In order to construct instances reflecting closely the practical problem setting of audit-staff scheduling, these definitions take the results of the above-mentioned survey among German CPA firms into account as far as possible.

We assumed that only two instance-related factors do have a major influence on the performance of a solution method, viz. the size and the tractability of the instance attempted.

Although the size of an instance is determined by different factors, statistical analysis of the results of the survey revealed that all these parameters depend on the length of the planning horizon. In the sequel, three types of instances will be distinguished with respect to their size: small (medium-term: 13 weeks with up to 30 auditors, 95 engagements, and 98,800 binary variables; medium-to-short-term: 20 half-shifts with up to 30 auditors, 300 jobs, and 9,000 binary variables; short-term: 40 hours with up to 5 auditors, 192 tasks, and 61,440 binary variables), medium-size (medium-term: 26 weeks with up to 55 auditors, 280 engagements, and 728,000 binary variables; medium-to-short-term: 30 half-shifts with up to 55 auditors, 550 jobs, and 16,500 binary variables; short-term: 80 hours with up to 6 auditors, 480 tasks, and 384,000 binary variables), and large instances (medium-term: 52 weeks with up to 125 audi-

tors, 880 engagements, and 5,948,800 binary variables; medium-to-short-term: 60 half-shifts with up to 125 auditors, 2,500 jobs, and 200,000 binary variables; short-term: 120 hours with up to 7 auditors, 864 tasks, and 1,244,160 binary variables). In addition, very small instances (medium-term: 13 weeks with up to 6 auditors, 10 engagements, and 10,400 variables; medium-to-short-term: 12 half-shifts with up to 6 auditors, 36 jobs, and 436 binary variables; short-term: 10 hours with up to 4 auditors, 36 tasks, and 2,160 binary variables) were generated. While these instances are too small to bear practical relevance, they can be solved to optimality with standard codes as LINDO and OSL and thus allow to draw some comparisons between the methods developed and exact algorithms.

The tractability of an instance is intended to reflect how easy or how difficult that particular instance is to solve. For the purposes of this study, the auditor capacities, the number of jobs some auditors have to work simultaneously on, and the number of precedence constraints for the medium-term, the medium-to-short-term, and the short-term planning, respectively, are assumed to be the only factor influencing the tractability of an instance: the higher the auditor capacities, the lower the number of jobs some auditors have to work simultaneously on, and the lower the number of precedence constraints are, the easier the corresponding instance is ceteris paribus to solve since its solution space becomes larger.

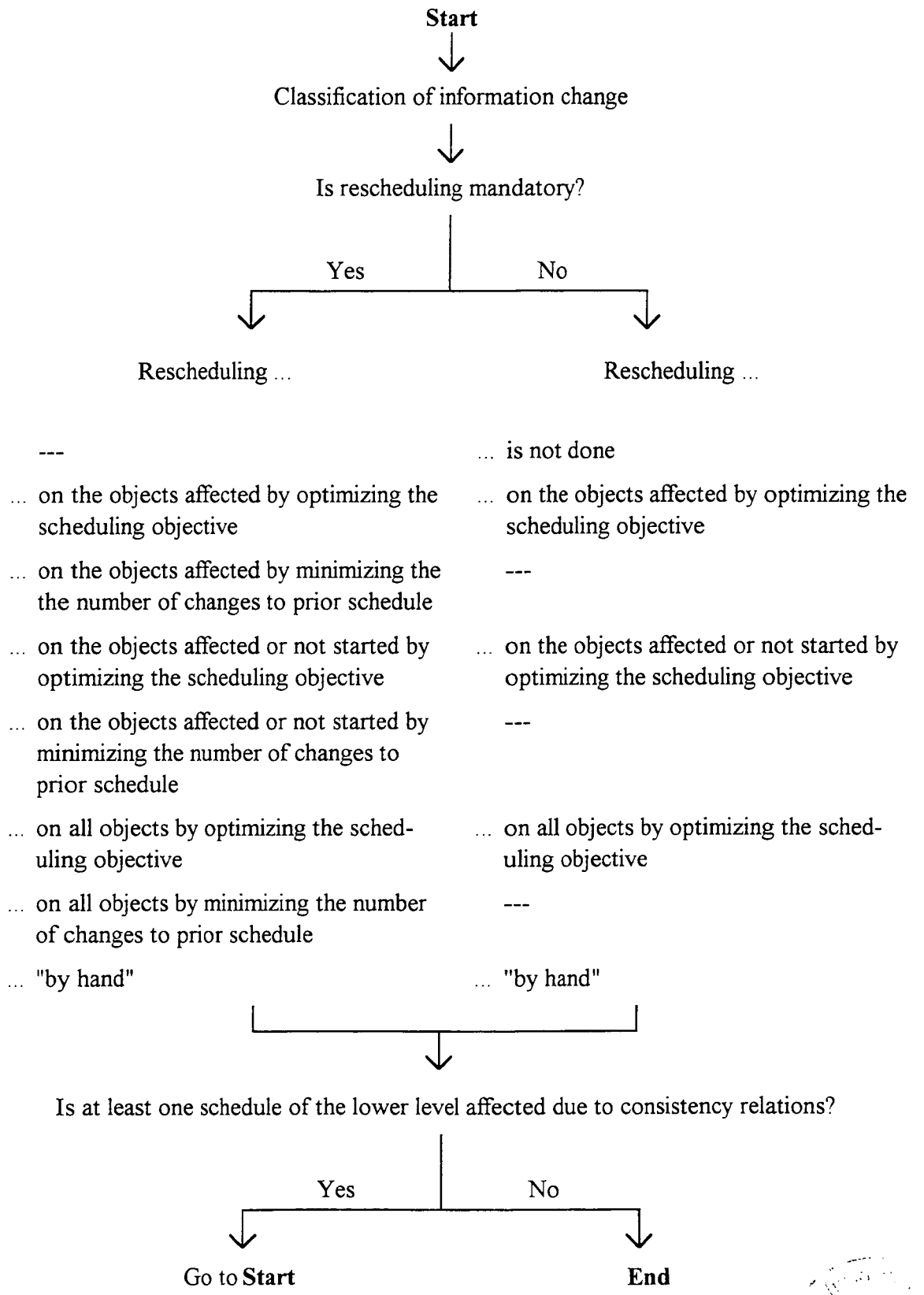
To summarize the computational experiments, we infer from the results obtained, that the algorithms outlined are capable of constructing feasible solutions in neglectable amounts of time. Moreover, the solutions produced are frequently near optimal. This means that the methods can contribute to a more rational and cost-efficient way of audit-staff scheduling in praxi.

## IV. Concept for Rescheduling

Up to this point the informations (assumptions, data) used by the models are assumed to be fixed. Unfortunately, one can observe frequent changes in praxi because of internal (e.g. illness of auditors) and external influences (e.g. new engagements). For this reason a system for audit-staff scheduling must not only provide powerful methods for solving instances, but is also required to allow to incorporate any kind of information changes in a flexible and easy way. On the other hand, attention must be paid to system nervousness (cp. Blackburn, Kropp, and Millen 1986, Carlson, Jucker, and Kropp 1979, Mather 1977, Minifie and Davis 1986, Sridharan, Berry, and Udayabhanu 1988, Wu, Storer, and Chang 1993). This means that slight alterations of informations are not desired to result in exaggerated changes of schedules. (For a more detailed and technical description cp. Salewski 1995, Salewski and Nissen 1993.)

Initially, a decision must be met between the very different concepts of flexible scheduling and rescheduling. Flexible scheduling means that every information change which is considered to be possible in future is reflected by decision rules with conditional probabilities. Because this concept needs such a prohibitive large number of data in advance and the informations required

*Figure 1: Characteristics of the concept for rescheduling*



for the deterministic case are already quite extensive the concept of rescheduling has been choosen.

Rescheduling is only done if an information change occurs. In this case the remaining periods up to the end of the planning horizon are rescheduled (scheduled again) under consideration of the new assumptions. Furthermore, for the medium-term planning the system is rolling forward the horizon (cp. Baker 1977, Baker and Peterson 1979, Campbell 1992). If e.g. the periods 1 to 13 are scheduled and after five periods due to an information change rescheduling is necessary then the actualized schedule consists of the periods 6 to 18.

For each of the three levels each assumption mentioned in section II is considered to be changeable except of the length of the planning horizons because this would destroy the hierarchical structure and directly imply inconsistencies. If a change occurs it can be classified according to whether or not it makes rescheduling necessary. While some alterations require rescheduling (e.g. rescheduling is mandatory, if a scheduled auditor becomes ill) others allow to improve the level-specific objective followed (e.g. rescheduling is optional, if due to a cancellation of vacation an auditor is able to work on an engagement). Thus, rescheduling with improving the level-specific objective is offered for both cases, while to avoid system nervousness minimizing the number of changes to the original schedule for mandatory rescheduling is possible, too. The methods needed to solve the corresponding problems are quite similiar to those described in section III. Additionally to these system-operated procedures, rescheduling "by hand" always is allowed.

To further dampen system nervousness the user can decide to fix the prior results - with respect to the assumptions - completely, partly, or not. For doing so, the objects concerned, namely engagements, jobs, and tasks, respectively, are classified to be in process or not and to be affected by the information change or not. Then, fixing the prior results completely means rescheduling only the objects affected by the information change, keeping some prior results is equivalent to rescheduling the objects affected or not started by the information change, while the last alternative incorporates all objects.

Finally, due to the consisteny relations rescheduling on an upper level may result in information changes for a lower level. To keep the schedules consistent information changes in an upper level automatically trigger rescheduling on the corresponding schedule(s) of the lower level.

The main characteristics of the concept for rescheduling are summarized in figure 1. Its main advantages can be seen in providing the user with an instrument for handling the frequent information changes, in guaranteeing the system-wide consistency of all schedules generated, and in allowing user-changeable procedures concerning the grade of alterations to prior schedules.

## V. Integration

While the functions of the single components, namely the medium-, the medium-to-short-, and the short-term level as well as the concept for rescheduling, have been discussed in the preceeding sections, the way how to integrate them into a whole system and how to use them will be explained in the following.

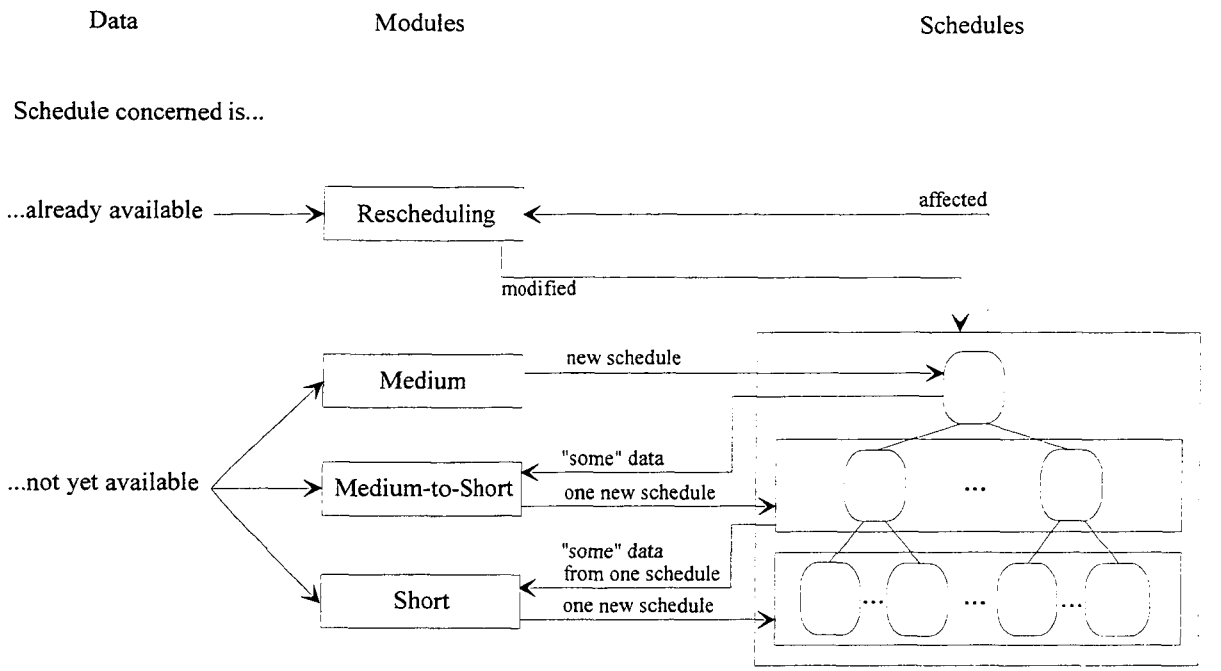
Assume that the parameters for the medium-term level have been specified. Then the medium-term schedule generation is triggered: the outcome is the best medium-term schedule according to the scheduling objective or - if desired by the user - a number of schedules from which one has to be choosen. In the case of only infeasible schedules being generated, information changes, or only if choosen by the user rescheduling is performed. Then the medium-to-short-term scheduling can take place in the same manner: for each period of the medium-term planning the medium-to-short term module may be started where some of the parameters from the medium-term level specified in section II serve as input and the others have been instantiated separately by the engagement managers. Afterwards for those periods of the medium-term planning where a medium-to-short-term schedule has been computed the short-term planning can be done in an analogous way: for each engagement scheduled within the planning horizon of a medium-to-short-term schedule, the corresponding program can be used where some of the parameters from the medium-to-short-term level specified in section II are used as input and the others have been instantiated separately by the responsible engagement manager. The options for rescheduling can be adopted analogously on the medium-term level.

Now a medium-term schedule and some medium-to-short- and short-term schedules are available. Other medium-to-short- and short-term schedules not yet generated may be computed as described above. (Note that these procedures are applicable even in the case of rolling forward the horizon of the medium-term planning.) Hence, the way of incorporating information changes concerning schedules already generated is of primary interest or in other words from now on rescheduling is mainly adopted.

Rescheduling takes place like discussed in section IV. To illustrate the proceeding assume a situation where for a week in which an engagement is already scheduled, processing is now disallowed by the client. Then rescheduling is done for the medium-term level, e.g. with the result that the engagement is scheduled in a different week with slightly changed auditor processing times. If none of the corresponding medium-to-short-term schedule exists already, rescheduling is finished, else it could be done for the week from which the engagement has been cancelled and must be done for the week where it is processed now. Furthermore, rescheduling on the short-term level must be done for each of those engagements where any changes have occured during medium-to-short-term rescheduling.

The design of the system as a whole is summarized in figure 2. Of special importance is the fact that the integration of the components into a single system does not only allow to generate a

*Figure 2: Design of the audit-staff scheduling system*




a (static) "snapshot" schedule which sometimes may be quite helpful, but allows as well for a (dynamic) use in the case of data changes.

## VI. Summary and Future Work

Based upon an empirical survey among the 200 biggest CPA firms in Germany an hierarchical modeling framework with the following three levels has been introduced:

- The medium-term planning assigns teams of auditors to the engagements. It constructs a schedule of all engagements, and determines the workload per auditor and week over a planning horizon of between three and twelve months.
- The medium-to-short-term planning disaggregates the results of the medium-term level for one week and all auditors. The outcome is a schedule for each auditor that covers - on the basis of periods of four hours - all engagements in which he is involved in the considered week.
- The short-term planning is based upon the results of the medium-to-short-term level for one week and one engagement. It assigns the auditors involved in the auditing of that engagement to the corresponding audit tasks and schedules these tasks. This is done for a period length of one hour.

For each of the levels methods capable of solving the underlying problems in neglectible amounts of time with acceptable results have been developed. Furthermore, a concept for re-

scheduling has been introduced which allows the user to handle information changes according to predefinable options in a flexible way.

On the basis of the system design introduced and by interviewing potential users a catalogue of requirements has been compiled, defining the systems functions, menu structures, input data, statistics, reports, etc. precisely. Before a prototype of the system can be completed the following has to be dealt with: implementation and systematic test of methods for the rescheduling (which may be similiar to those of the single levels), definition of data structures as well as data base schemes, and programming of an user-friendly surface. Finally, the prototype must be tested in praxi for the purpose of evaluating how well it meets practical requirements. Eventually, this will results in some slighter final modifications.

## Acknowledgement

The author is indepted to Professor Andreas Drexl for his critical and helpful comments as well as to Andreas Schirmer for improving the phrasing of this paper.

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