

Modelling and Solving Workforce Scheduling Problems

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Abstract. Workforce scheduling is known as a complex and highly constraint problem. In the last few years the problem even become more complex due to the deregulation of laws limiting working times, flexibility and opening hours for shops at least in Germany. This paper describes an intelligent workforce scheduling component which shall be incorporated in a commercial workforce planning and scheduling system. Main points are the modelling of the workforce scheduling problem and a heuristic to provide a solution that regards the given hard and soft constraints.

Introduction

As cost of personnel has become one of the most significant factors in most service oriented companies it seems clear that one of the main goals when scheduling or improving business processes is to minimize these costs. This also means that one tries to use the minimum necessary personnel to fulfil the tasks to be done but this in the required quality. On the other hand the use of high quality and professional staff brings main advantages in customer satisfaction. Additionally, we have to respect the fact that effective deployment of workforce has not only direct monetary effects, also a higher motivation of the employees can be achieved [Geb04].

Therefore workforce scheduling has become increasingly important to provide the firms with schedules that present the right number (which means minimal) of the right persons (which means with the necessary qualification) at the right time. For the customers the goals are a little different: they demand a high number of highly qualified service personnel in order not to have to wait to long for being served. And last but not least, a schedule that respects the wishes and personal plans of the employees will lead to more satisfaction on their side.

But several other constraints have to be regarded as well when trying to schedule the staff for a given time period. These reach from guaranteeing a minimal number of staff to all legal restrictions e.g. those for breaks.

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Thus we start with a description of a workforce scheduling problem. This is likely to be found in several stores, retail or other service companies. The main goal of workforce scheduling is to find a schedule which is basically an assignment of persons to time intervals. With the schedule the demand of staff shall be fulfilled and all the other constraints have to be regarded and most often a cost function shall be optimized.

Among the requirements and constraints are:

- the number of personnel must fit the demand,
- the qualification of the scheduled staff must fit the needs,
- the different types of contracts have to be regarded,
- the legal regulations have to be obeyed, e.g.
 - o staff should not work longer than specified in contract
 - o staff should not work more than one shift per day
 - o holidays have to be regarded,
- different shift models may occur (one, two, three shifts etc.),
- breaks have to be regarded.

An important sub-problem when scheduling the workforce is the break placement problem, which has to be done for each assignment of each employee. While an employee has a break he can not cover the workforce requirements. So breaks reduce the number of available employees. As a consequence break placement is an aspect which has to be coped with simultaneous to the staff assignment. In the worst case a bad break placement increases existing periods of understaffing, in the best case one can reduce overstaffing. But break placement has to respect a number of rules based on laws and other restrictions as well.

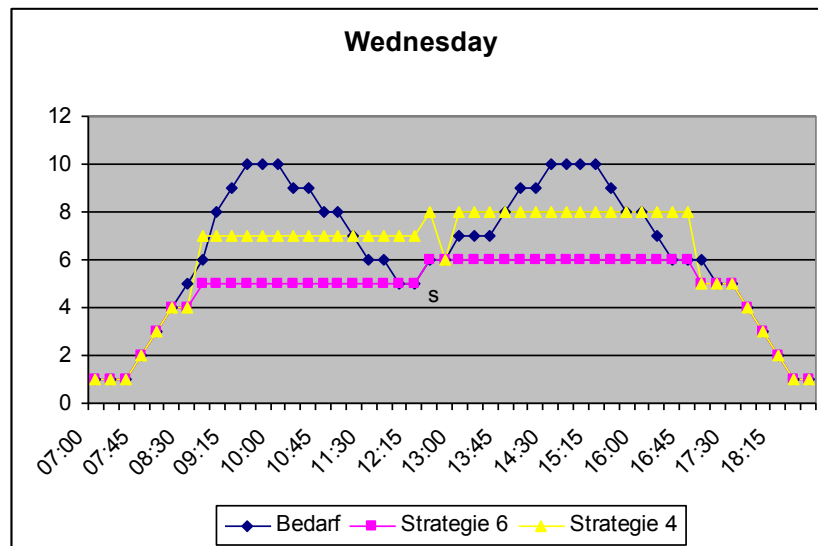


Figure 1. Workforce scheduling: demand and possible solutions

The goals the schedule shall reach can be formulated in terms of

- overtime: try to have no overtime, which means that there are time periods with more persons than needed
- undersupply: try to have no undersupply, which means that there are time periods with less persons than needed
- minimal cost schedule: try to have a schedule where the least costs arise.

Most often a combination of these goals seems adequate. The demand is given by typical numbers e.g. calculated from forecasts. Figure 1 shows such a demand for one day (Bedarf) and two possible schedules (Strategie 4, Strategie 6) that do not meet the demands. The schedule here is presented cumulative not by the list of persons which is another kind of presentation.

The rest of the paper describes an intelligent workforce scheduling component. First a model on the basis of other scheduling problems is presented. Then the heuristic strategy for constructing a weekly schedule is described.

Modelling the Workforce Scheduling Problem

According to our modelling approach of scheduling problems we will also use the 7-tuple (O, R, P, HC, SC, G, E) used for several scheduling problems [Sau06] to describe the workforce scheduling problem. For the workforce scheduling example the sets mean:

- **Orders**
are the demand of personnel, i.e. the given workload profile
- **Resources**
are the staff with their individual quality profiles and their individual contracts
- **Products**
are the services the staff can provide
- **Hard Constraints**
are legal and other restrictions, e.g. maximum working hours, maximum numbers of shifts, not to work in two following shifts
- **Soft Constraints**
represent the constraints we want to achieve, e.g. not to have overtimes, not to have undersupply, have a fair distribution of the workload to the personnel, sometimes overtime may be allowed, sometimes undersupply may be possible, etc.
- **Goal functions**
Goal functions can give an impression of the schedule quality. They may be time oriented, e.g. sum of overtimes, sum of overtimes and sum of undersupply, etc.
- **Events**
events have to be formulated for the reactive scheduling part of the workforce scheduling problem, e.g. ill persons, late persons, persons missing

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for other reasons, changes in demand, etc. In our first version the reactive workforce scheduling problem is not regarded.

Compared to other problem representation based on this modelling approach, e.g. transportation scheduling [Sto04], here the resources have to be described in more detail. The schedule to be created shows the temporal assignment of the personnel.

Search Space for the Workforce Scheduling Problem

According to the modeling of the workforce scheduling problem the problem space can be presented as an And/Or tree. The tree represents the problem structure described above and already includes some of the constraints. One of the main differences to the other scheduling problems is that that combination of persons working together is not known in advance. This means that on the level of personnel group a subset of the personnel is to be found, i.e. a node represents a subset of the personnel. The solution is a subtree of the And/Or-tree for which holds:

- it contains the root node,
- for every And-node all successors are in the solution
- for every Or-node one successor is in the solution.

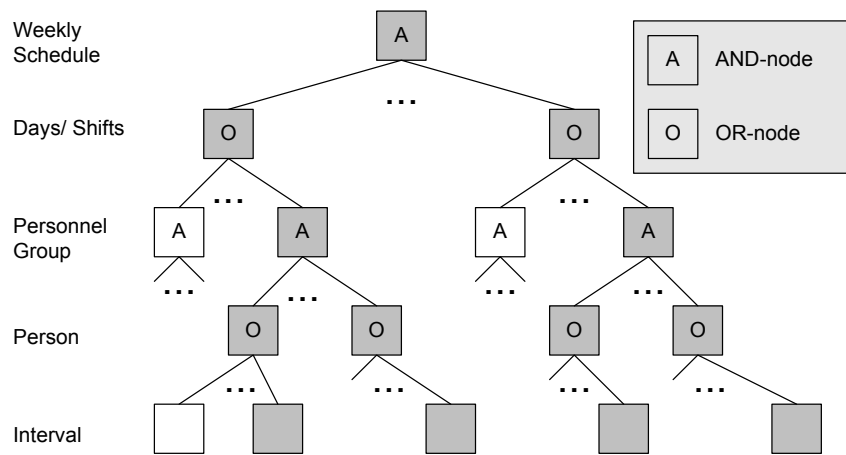


Figure 2. AND-/OR- tree for workforce scheduling

In figure 2 a solution is depicted by the darkened nodes. The complexity of the solution space [Sau04] for such presentation is

$$L = (I^P * PG)^D, \text{ with}$$

- L number of solutions
- D number of days/ shifts
- PG number of staff groups, in the worst case this may be 2^P

- P number of persons
- I number of intervals per person.

This means that even for small problem sizes the complexity of the search space is very high. Additionally, it is not possible to estimate the impact of the constraints on the size of the solution space.

Heuristic for solving the WSP

The general phases of the workforce scheduling process as presented by Ernst et. al. [EJKS04] are:

- demand modelling
- days off scheduling
- shift scheduling
- line of work scheduling
- task assignment
- staff assignment

Within the project only two of the problems have to be solved, because the other tasks are already exist. In the retail trade business one can state a flexible demand model, which means that forecasting methods have to be used to determine future demand. The workforce requirements forecasting is done by an already existing module and gives a demand for a fixed period, in this case a week, showing the employees needed for the time periods of the days.

```

/** Basic workforce scheduling strategy
WHILE days to schedule {
    select most difficult day to schedule
    calculate maximum interval
    select staff group for the day
    WHILE demand {
        IF conflict
            THEN solve_conflict
        ELSE
            select best suited person
            select best suited interval
            plan person
            reduce demand
    }
    remove scheduled day
}

```

Figure 3. Basic scheduling strategy

Main input-data is the set of employees, each of them with potential different restrictions for assignment and break placement. This set of employees consists of two subsets. First is the primary pool, containing all employees working mainly for the organizational entity for which the schedule is computed. The second subset, called the secondary pool consists of employees that may be scheduled additionally but mainly are working in other entities.

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In a first step several heuristics were checked that could be useful for solving the workforce scheduling problem [GT04]. Alternatively a solution on the basis of constraint programming packages was evaluated. But in most cases several constraints especially individual preferences could not be realized by the existing approaches. Thus a constructive heuristic was developed that incorporates the scheduling behaviour of human planners as well as it tries to respect the individual constraints of the employees.

The main scheduling scheme looks as presented in figure 3. The basic approach is to construct the schedule in several steps, starting with a schedule neglecting breaks and in a second phase adding the breaks. Another general heuristic used is that of problem decomposition, i.e. the schedule is constructed day by day. The main scheduling heuristic then tries to find the right person for a given time period.

In the heuristic scheduling knowledge is incorporated in the “select” statements and in the conflict resolution, e.g.

- Select most difficult day: a difficult day is a day with high demands in different times
- Select staff group: the staff group is composed of those persons that can be scheduled principally for that day and then reduced to the persons in the schedule
- Select best suited person: this combines a number of rules, e.g. persons with most remaining working time, persons that exactly fit an interval, persons with longest remaining working time interval, persons with preferences on that interval
- Select best suited interval: within the demanded interval a personal interval is chosen that best fits the demand and the working time constraints of the person.

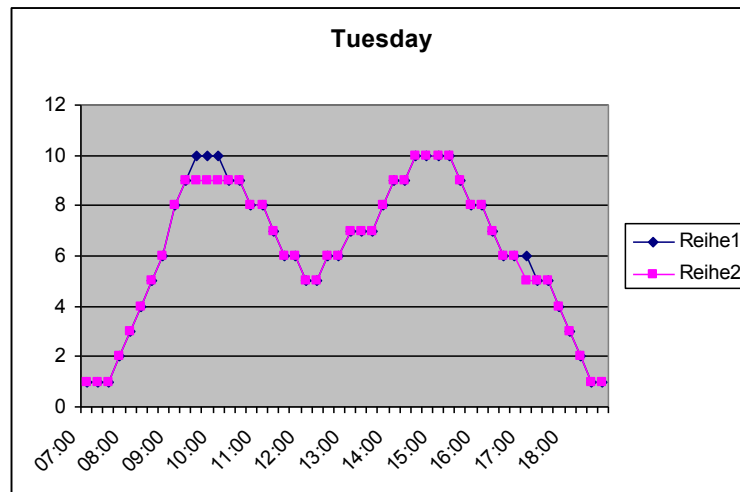


Figure 4. Matching curve

In a second phase the necessary breaks are added to the schedule, which sometimes lead to additional requirements in personnel, which then also is added to the schedule.

The result is a daily workforce schedule, that shows who is working in which shift and time interval. Figure 4 shows a matching curve for a schedule showing an “optimal” result.

Related Work

Often the retail trade workforce scheduling problem is treated as a scenario comparable to the workforce scheduling problem in call centers. And in fact there are a number of similarities [EJKS04]:

- workforce requirements are dynamic fluctuating and therefore change from day to day
- shifts can change in their length and starting points
- over- and understaffing are possible and shall be minimized and can therefore be treated as a soft constraint
- the number of possible shifts can become intractable high.

Generally, several systems for staff scheduling, crew scheduling and nurse rostering have been proposed and some systems are available at the market. But in nearly all cases the solution is restricted to a dedicated problem and thus only concepts and ideas can be used for other similar problem scenarios.

Most commercial systems have only simple scheduling capabilities and leave the scheduling tasks to the user of the system. But surprisingly there has not been done much research done in the area [EJK+04]. Most systems base on the constraint based approach, i.e. they see workforce scheduling as a constraint satisfaction problem and all constraints used are interpreted as hard constraints. Examples of such systems are systems developed with ILOG tools [Har07, ILOG07] or standalone systems like OC:Planner [Tol07]. Other work tries to solve the staff scheduling problem with integer programming tools but here only a few of the constraints, especially of the soft constraints, are regarded [BBD03].

Summary and Future Work

Within the project a first prototype of a heuristic staff scheduler was developed which is now part of a commercial product in the staff planning area. The system combines general heuristic strategies with specific heuristic rules from the human schedulers and presents a solution that is visualized in an interactive staff planning system. Figures 5 and 6 give an impression of the user interface. Figure 5 shows the cumulative view of the demand and its fulfilment, figure 6 shows the detailed information for the staff.

In next steps it has to be evaluated how flexible and extensible the approach is, i.e. how complex it is to integrate new requirements or constraints.

Further research can be done on the integration of heuristic based and constraint-based approaches to solve the workforce scheduling problems.

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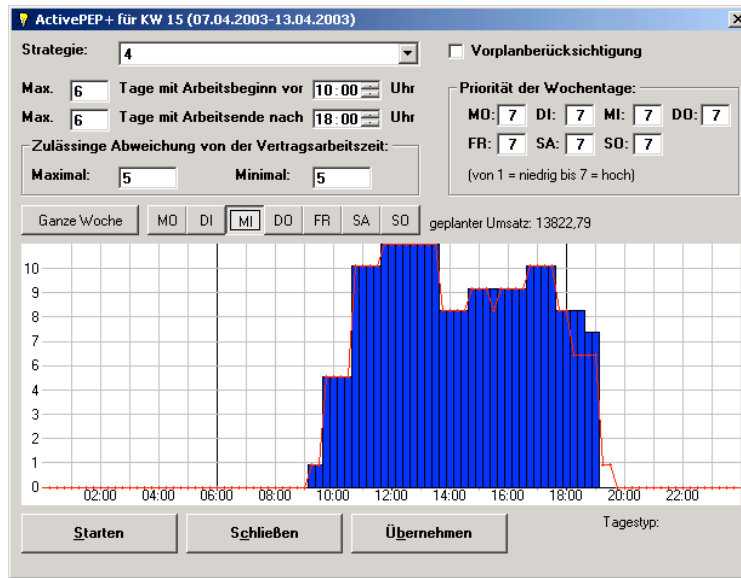


Figure 5. Matching curve within the goal system

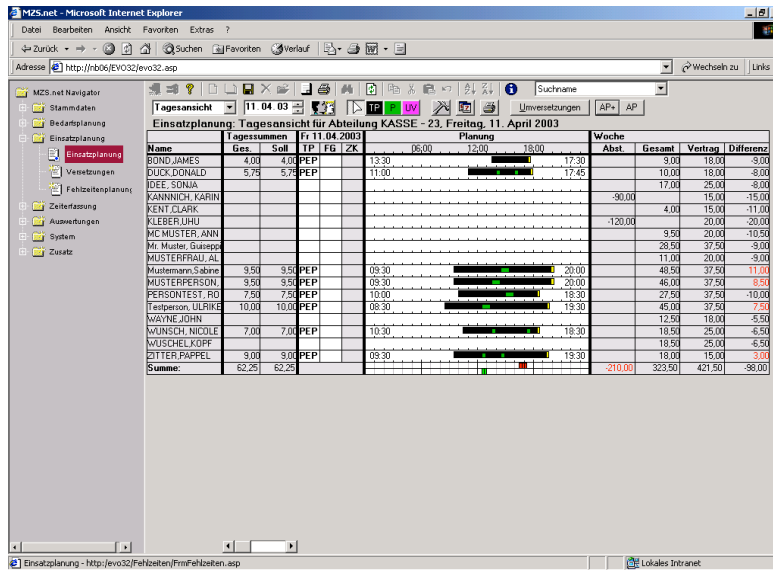


Figure 6. Example of detailed staff schedule

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