Scheduling Matters – Some Potential Requirements for Future Rostering Competitions from a Practitioner's View

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Abstract Scheduling algorithms have made impressive advances. Many objectives can be reached within reasonable runtime, as the previous International Nurse Rostering Competitions (INRCs) showed. As usual, these improvements have raised practitioners' expectations, who, in this case, are consultants and researchers in working time and shift scheduling.

This paper highlights potential additional requirements in two areas and provides input for possible future rostering competitions. Firstly, some requirements regarding scheduling objectives are raised that are important for *people* – because it is not sufficient to simply fill rosters, and income, health, safety and well-being are heavily influenced by work schedules. It is therefore necessary to include rules that consider specific features of shifts and sequences of work (e.g., average hours per week). Secondly, a vision of a meta-requirement is raised. It is not enough to fulfill the specified requirements as effectively as possible. In a real-life setting, quite often requirements can be changed. Consequently, it would be advantageous to understand which schedule requirements cause bad solutions in order to be able to identify possible changes that encourage better solutions.

Introduction

Employee work scheduling has a long history. By the 1970's and 80's algorithms for better schedules had been developed [1-3], and they already focused, in part, on health and well-being. Since the 90's many automatic and semi-automatic algorithms for work scheduling have been developed to satisfy scheduling requirements in different work contexts, e.g., nursing,

manufacturing and industrial complexes, and air transport. Although some automatisms for scheduling were used, manual interaction remained important for optimization and adaptation of the resulting schedules.

The general development of scheduling and optimization led to highly varied algorithms and approaches which are difficult to monitor and evaluate. The two previous International Nurse Rostering Competitions (INRC) in 2010 and 2015 helped to improve and compare algorithms [4,5]. The background of this paper is roughly 20 years of experience in consulting and research in the field of working time and rostering. Our consulting services, which we run mainly in Central Europe, mostly include the generation of rosters and working time arrangements that

- are favorable in terms of economics
- comply with the law,
- and do not impair health and well-being.

We are using several techniques to accomplish these aims, including optimization algorithms [6]. Our research is part of the interdisciplinary research community of the international Working Time Society that has similar aims, including a strong focus on health, well-being, and accident risks, among other outcomes. Knowing the difficulties of rostering, we greatly appreciate the effort and achievements of the PATAT community. We are glad to contribute our vision of future directions for the community.

From the perspective of practitioners and researchers, we raise ideas in two domains. The first is difficult but important. It addresses the pay, health, safety, and well-being of the employees. We describe the working hour arrangements required to address these issues, as well as their scientific background. The second dimension we consider to be even more challenging. It involves helping schedulers understand interactions between schedule requirements, allowing them to identify where small changes to some requirements result in much better solutions.

Employees as humans

Work schedules influence not only working outcomes, but also the living and working conditions of employees. Although improving knowledge of these effects is a huge and evolving research field,

many aspects have become quite clear. The basic mechanisms stem from humans as biological and social beings.

From a biological perspective, the sleep/wake cycle has an extensive influence on us. This circadian rhythm is determined by both our internal (the "master clock") and external zeitgebers (most importantly light, but also timing of meals, sleep and other behavior). The sleep/wake cycle can be disturbed by exposure to light and activity (e.g., work) at night, a time when we are programmed to be in darkness and sleep. Consequently, rhythmic body functions, such as hormones or body temperature, de-synchronize with the circadian rhythm. This desynchronization can cause problems, such as fatigue during work, sleep problems after night shifts, and mid- to long-term health impairments [7].

These effects can be more pronounced in some individuals than in others, partly due to inter-individual differences in the inner clock (some people can be characterized as early and some as late "chronotypes" [8]) or flexibility in sleep behavior. These individual factors also vary with age. For example, with increasing age, tolerance of rotating shift work or night work usually decreases and the chronotype changes towards "morningness" [9].

However, biological rhythms are not the only ones that affect the life of humans. At least in western societies, there is a history of social activities occurring mostly in the evenings and on weekends, forming a normative social structure or "social rhythm" [10,11]. Therefore, working hours that interfere with this social rhythm, particularly working on evenings and weekends, are more likely to impair social well-being and work-life balance [12]. In the case of shift work, quickly rotating schedules with three or less shifts of the same type in one block interfere less with socially valuable time than slowly rotating schedules, in which a week or more of unsocial work hours, such as late shifts, is common and significantly impairs social interaction for a long period.

In addition to the daily timing of work, the number of working hours per day and per week affect safety, health and social well-being. For example, an exponential increase in accident risk after 8-9 hours on duty is well documented [13,14], and extended weekly working hours have been shown to increase the risk of health problems and social impairments [15]. In several cases, a reduction in working hours has been shown to improve employees' health and job satisfaction [16,17]. In one of these studies, working hours were not only reduced but the shift schedule was also changed from long blocks of work (3 morning, 3 late, 3 night shifts followed by 3 days off) to shorter blocks with

fewer night shifts and longer rest periods (2 morning, 2 late, 2 night shifts, followed by 4 days off) [12]. This evidence indicates that schedules with reduced working hours per week produce healthier shift patterns.

Several factors can protect against the negative effects described above. Rest breaks, especially during a shift, can reduce work load and longer rest periods between two shifts can increase opportunities for sufficient sleep and rest [13,18]. Additionally, control over working hours is an important resource, which buffers (but not eliminates) the negative impact of irregular or long working hours on health and work-life-balance [19].

Work schedules can thus have consequences for the following factors:

- Accident and error risks: In a meta-analysis, Fischer et al. [14] found increased accident and error risks due to work hour characteristics such as
  - o shift length (12h-shifts are associated with almost twice the accident risk than 8h-shifts),
  - o working a night shift (increased accident risk by ca. 33% compared to working a morning shift),
  - o having a rest break (can reduce the accident risk by about half compared to no rest break), and
  - o cumulative effects of successive shifts (e.g., the fourth night shift shows a risk increase of 36% compared to the first night shift).
- Health, which is most affected by night work, irregular and unpredictable work hours, number of hours per week, and weekend work [7,15,18].
- Social well-being, which is mostly affected by work on evenings and weekends, and irregular or unpredictable working hours [12].

Due to the multifactorial, and often interdependent, relations between work schedules and the consequences described above, optimization of shift schedules from a health and social perspective is challenging, especially when combined with other requirements caused by staffing requirements that vary at different times, individual preferences, and working time law and regulations.

Legal and practical aspects

Employee rostering is typically embedded in a legal framework. However, there is a wide variety of approaches to dealing with shift work. Within the European context, especially in Central Europe, there are many prescriptive rules that limit scheduling, e.g., a minimum rest period of 11 hours between shifts is common in many countries and sectors. Additionally, there are many rules on payment, especially on overtime and supplements. In many countries, limits and rules refer not only to single shifts but to stretches of work. For example, working hours per week are limited to 48 hours, on average, and 50 hours in a single week. Additional hours have to be averaged out within a prescribed period (e.g., 4, 13, 17, 52 weeks) or otherwise employees are entitled to additional payments or rosters become illegal. Some countries (e.g., Australia) and sectors (e.g., transportation) focus more strongly on accident risks.

Although it is impossible to provide any complete list of rules (it is impossible for Austria due to the number of sectors and company-level agreements), there are some general rules related to:

- maximum hours per week / averaging period,

- minimum and maximum hours handed over from one period to the next,

- minimum rest hours after a shift depending on the number of consecutive hours worked,

- the possibility of shortening some rest hours if others get longer,

- extra rules for shift length on weekends (e.g., 12h-shifts),

- exceptions rules (e.g., under specific circumstances longer working hours may be legal for some weeks), and

- distinctions between types of time with different rule sets referring to work content (e.g., normal work, work with standby times, being on-call) or to the time of day or day of week (e.g., night, evening, or weekend work).

This rather long list, however, reflects only a small fraction of the actual complexity.[1]

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[1] For the connoisseurs of complexity: In some laws, the "working day" is not related to a calendar day or 24:00 hours (e.g., a working day may start at 2:00 am, last for 6 hours, and the following working day start at 8:00 pm). So the start of the "day" may move. Probably it does not come as surprise that a week also does not necessarily start at 00:00 hours.

Potential requirements for future rostering competitions

The Second INRC [5] dealt with two types of constraints concerning legal requirements and working conditions: contracts and shift types:

*"**Contracts:** Each nurse has one specific contract (e.g., full-time, part-time, on call). The contract sets limits on the distribution and the number of assignments within the planning horizon. In detail, it contains*

- *minimum and maximum total numbers of assignments in the planning horizon,*
- *minimum and maximum numbers of consecutive working days,*
- *minimum and maximum numbers of consecutive days,*
- *a maximum number of working weekends in the planning horizon, and*
- *a Boolean value representing the presence of the complete weekend constraint to the nurse, which states whether the nurse should work both days of the weekend or none of them.*

(…)

***Shift types:** For each shift type (e.g., early, late, night), its minimum and maximum numbers of consecutive assignments and a matrix of forbidden shift type successions are given. For example, it may not be allowed to assign an early shift the day after a late shift." [5, p. 2]*

To some degree, contracts and shift types requirements can accommodate legal, health and well-being considerations. For example, minimum rest hours between duties can be addressed by forbidden shift sequences or maximum shift length can be addressed when designing shifts. With a small number of different shifts it might be easy to enumerate all feasible and forbidden sequences. With a larger number of shifts (e.g., 10-20) over longer stretches (e.g. 14 days) this becomes very cumbersome.

We suggest the following extension to these two types of constraints for future rostering competitions:

Rules: Hard and soft constraints regarding hour and shift counts over repeated periods of time (e.g., n weeks) or prescriptions regarding some categories of time (e.g., 36h of time off) and the expression of constraints built with such definitions.

Examples for such constraints are:

- The average working hours of an employee should be <= 40h/week.
- The maximum working hours should be <= 48h/week.
- Each week should have a rest period of 36h.
- After a night shift, employees should have a rest period of 48h.
- For each night shift of at least 6 hours, the employee receives 2 hours of paid rest.

Setting additional constraints of this nature may assist to reduce accident risks and enhance the health and social well-being of the employees.

Interestingly, the First INRC [4] had a few additional requirements, e.g., minimum and maximum numbers of consecutive free days, a maximum number of consecutive working weekends, a maximum number of working weekends in four weeks, number of days off after a series of night shifts. Overall, the requirements were similar.

Our vision: Understanding the network of requirements

Constraints are not always as well-defined as one might assume. They might have been determined without adequate analysis or by applying wrong or outdated assumptions. Rechecking constraints is part of many of the over one hundred real-life cases that we deal with at XIMES each year. Indeed, very often constraints are changed after deeper analysis. Even legal requirements are often ill-defined. The German saying, "two lawyers give three opinions", is very often true! Reviewing all constraints, however, is impractical for companies and consultants. It would be just too much work and often prohibitively expensive.

As a consequence, it would be very advantageous to focus this rechecking and thinking about alternative options on those constraints that, if modifiable, would have the greatest positive impact.

It may be surprising, but even legal constraints are not always as strict as they may appear. Firstly, new options for interpretation may emerge while discussing them. Secondly, some legal rules can be changed if a strong enough case is presented. This clearly is easier in small countries like Austria with a lot of power given to the social partners at industry and company level. There are similar developments in many countries, however. Some countries even allow for a broad range of actions if you can show that they are beneficial to employees.

Correspondingly, having (semi-) automatic support to understand why, for example, all potential solutions are inconsistent with a given set of constraints would greatly alleviate the tedious task of validating (sets of) constraints individually. Is it a small number of constraints that lead to inconsistency or what are the mechanisms that make the problem specification unable to permit solutions? Would the rostering solutions improve in terms of health and well-being if some constraints were changed?

Techniques, such as the enumeration of maximum unsatisfiable sets [20], that are incorporated into well-established tools [21] can help tremendously to answer these questions.

Understanding the consequences and limits of hard constraints is difficult. The situation with soft constraints is even worse. In practice, schedulers are often confused when a minimal change in one weight of a soft constraint leads to substantially different solutions or, conversely, why massive changes have no impact on the roster at all. Are we able to develop answers to help us understand these conundrums?

Conclusions from a practitioner's point of view

The definition of additional constraints on relevant working hours can enable us to develop work schedules that minimize impairments of worker safety, health and well-being, apart from observing legal requirements and fulfilling staffing requirements. Such improved work schedules would benefit not only the workers but also the companies e.g., by reducing sickness absence [16] and thus saving expenses. Additionally, in countries with social security systems, a healthier workforce can save costs of welfare systems for long-term sick leave, disability pension, and accident insurance. An automated identification of hard and soft constraints that impair the finding of good solutions can have a great impact on using automated scheduling in practice. It would provide schedulers with

essential information on which constraints to adapt in order to obtain better work schedules. This would make scheduling much easier and faster with (semi-) automatic support.

PATAT and the INRCs have enabled great accomplishments in rostering, but there are still opportunities for us to lift our approaches to the next level. Let's start now!

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