Personnel scheduling considering employee well-being: insights from case studies

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Abstract

This research is concerned with new metrics we suggest for measuring employee well-being to be included in personnel scheduling. The well-being of employees has attracted the interest of researchers mostly in the field of Occupational Medicine, over the past decade. The aim of this paper is to bring the issue of employee well-being to the Timetabling community. We provide an overview of well-being literature followed by a description of the well-being measures that we propose to be included in the objective function while generating a roster. These measures include work-life balance measures, Fatigue and Risk indices, and compliance with Health and Safety Executive (HSE) guidelines. As an experimental environment, we use three case studies of personnel scheduling, which are of very different nature: scheduling of fixed shift patterns, nurse rostering and cyclic scheduling of flexible shifts in a call-centre service industry. Our aim is to investigate to what extent employee well-being can be improved while maintaining high performance of rosters. We analyse and compare proposed rosters generated manually and by computerised algorithms, with and without well-being measures.

Key words: personnel scheduling, well-being measures, fatigue, case studies

1. Introduction

Personnel scheduling has been a subject of interest within both Operational Research and Artificial Intelligence research communities for a number of decades. It can be stated as an assignment problem in which personnel are assigned to shifts to cover the demand for resources that varies over time (Ernst et al. 2004b). The assignment is subject to given rules/constraints, which are used to apply restrictions to the timetable. These are usually divided into two categories: "hard" restrictions which are rigidly enforced and "soft" restrictions whose satisfaction is desirable but not essential because it is often difficult or impossible to satisfy all of them. In general, the level of satisfaction with the soft constraints in a generated timetable determines its quality. Usually, workforce planning/staffing, which deals with strategic decisions related to the optimal size or mix of a workforce, precedes timetabling, i.e. in timetabling it is assumed that staffing levels are given. Also, in each time period of the rostering horizon the demand is calculated and serves as input to timetabling. In practice, personnel scheduling problems can be very hard to solve, and their manual solution requires much effort.

Separately from these research efforts, there is increasing research into well-being of employees related to work, but mostly reported in the field of occupational medicine. In the literature review of the effect of employee well-being on their work, it was stated that employees high in well-being are generally more productive at work, have higher incomes, and have better physical and mental health (Jeffrey et al, 2014). There is evidence that improving employee well-being improves organisational outcomes and also has impact on sickness absence, presenteeism, employee engagement, retention and performance (Donald et al, 2005). This particularly applies to tasks that require vigilance and monitoring, decision making, awareness, fast reaction time, tracking ability, and/or memory. Generally, personnel scheduling methods do not measure employee well-being in any formal or objective way, apart from imposing some constraints, hard or soft, to reflect the EU Working Time Directive (2003), restrictions on night shifts, etc. The aim of this paper is to bring the research into well-being of employees related to work to the attention of the timetabling community. The paper is organised as follows. First a literature review of main findings about well-being at work is given, followed by a description of the proposed measures for employee well-being. We report our insights into these measures and their effect on the performance of the rosters based on three case studies.

2. Literature review on well-being at work

We group the papers into different categories based on aspects of employee well-being they investigate. The categories and the selection of relevant papers are presented in Table 1.

There is a large number of papers that report on the **effects of well-being on organisational outcomes**, such as productivity, absenteeism, retention, etc. An extensive piece of research was carried out by Donald et al. (2005), which involved 15 different organisations in the public and private sectors in the UK spanning a range of occupations, from professional to administrative and manual roles. Young and Bhaumik, (2011) carried out a Health and Well-being Employee Survey for Department for Work and Pensions in the UK. The conclusions were that better psychological well-being resulted in higher employee productivity; there was an association between high employee engagement, positive views about work life balance and high employee retention/low sickness absence. Factors that affect the job performance, retention and sickness absence were investigated by Zedeck et al (1983), Diener and Seligman (2004), and others. Warr and Nielsen (2018) discussed different types of context-free and job-related well-being, and reviewed research into association between well-being and work performance through specific factors such as being creative or proactive at work.

Many employees work alternating shifts, which usually last between 6 to 12 hours (Harrington, 2001). The traditional three 8-hour shifts start at 06:00, 14:00, and 22:00 hours. However, there are many variations of shifts and employees can rotate through different shifts with variable degrees of speed of rotation and direction of rotation. A summary of **effects of shift work on health and safety** reported by Harrington (2001) initiated other research into design of work schedule (see for example, (Folkard et al, 2005, Muecke, 2005, Fransen et al, 2006, Lowdan et al, 2010, Kubo et al, 2011, Schernhammer et al, 2011; Ferri et al 2016; Gärtner et al, 2019, etc.).

Table 1. Selection of the literature on well-being at work

Topic of the research	**Publications**
Effects of well-being on organisational outcomes	(Zedeck et al, 1983), (Diener and Seligman, 2004), (Donald et al, 2005), (Young and Bhaumik, 2011), (Warr and Nielsen, 2018),
Effects of shift work on health and safety	(Folkard et al, 2005), (Muecke, 2005), (Fransen et al, 2006), (Lowdan et al, 2010), (Kubo et al, 2011), (Schernhammer et al, 2011), (Gärtner at al, 2019)
Giving staff control over their shift patterns	(Ala-Mursula et al 2006), (Ingre et al 2012)
Effect of overtime work on hazard rate and health	(Smith et al, 1998), (Dembe et al, 2005), (Bell, 2012), (Wong et al, 2019)
Different shift lengths	(Cunningham, 1982), (Northrup, 1989), (Tucker et al, 1996), (Ellis, 2008)
Rest days	(Tucker et al, 1999), (Flo et al, 2014)
Delaying shift start and end times	(Rosa et al, 1996)
Forward-rotating schedules vs backward-rotating schedules	(Barton et al, 1994), De Leede and McCarrick (2011)
Comparison of fixed shifts to rotating shifts	(Martens et al, 1999), (Fereshteh et al, 2011)
Regular work more than 48 hours a week	(Spurgeon et al, 1997)
Night shift	(Khaleque, 1999), (Gander et al, 2007), (Ferri et al, 2016)
Comparison of different shift patterns	(Baxter and Mosby, 1988)

The positive effects of **giving employees control over their shift patterns,** so-called self-rostering, were reported by Ala-Mursula et al (2006), Ingre et al (2012), etc.

A number of papers quantified the **effect of overtime work on hazard rate and health**. Dembe et al (2005) found that working in jobs with overtime schedules was associated with a 61% higher injury rate compared to jobs without overtime. In line with that, working at least 12 hours per day and at least 60 hours per week was associated with a 37% and 23% increased hazard rate. Smith et al (1994) investigated the risk of injury at an engineering firm and found that it was 20% higher for staff on night shifts than for those on day shifts. Additional research on this topic includes (Bell, 2012) and (Wong et al, 2019).

Particular attention was paid to the research into the effect on well-being of different shift patterns, timings, lengths and distribution of rest days. There is considerable research into impacts of **different shift lengths**. Long shifts (e.g. 12 hour shifts) were popular with employees, largely because of the longer periods of time off and greater freedom on weekends and evenings (Northrup ,1989). However, Tucker et al (1996) reported that towards the end of a 12 hour shift there is a risk of fatigue and decreased alertness of employees especially when the job role is highly monotonous and sedentary.

The distribution of **rest days** was investigated, especially between day and night shifts, and their effect on alertness, chronic fatigue and other health problems were investigated by Tucker et al (1999), Flo et al (2014), etc.

Delaying shift start and end times also have an effect on the performance at work (Rosa et al, 1996).

Rotating schedules can move forwards (so-called **forward-rotating schedules**), which means that employees shifts progress from morning to afternoon to night in a clockwise direction, and opposite i.e. backward (so-called **backward-rotating schedules**). The research into the effects of the two types of rotation and of alternating them was conducted by Barton et al (1994) and De Leede and McCarrick (2011).

Generally employees can work fixed shifts, which are always the same, or rotating shifts which change often on a weekly basis. Research into **comparison of fixed shifts to rotating shifts** revealed it was generally more difficult for the body to adjust to rotating shifts and working shifts might lead to health complaints **(**Martens, et al, 1999, Fereshteh et al 2011).

Negative effects of **regular work more than 48 hours a week** and **night shifts** were reported by Spurgeon et al (1997) and Khaleque (1999), respectively. Ferri et al 2016 concluded that nurses with rotating night schedules had a higher risk of both job dissatisfaction and undesirable health effects. It was also found that night work and schedule instability were independently associated with more fatigue measures than was total hours worked (Gander et al, 2007).

Baxter and Mosby (1988) compared **different shift patterns** by using a function to penalise long work periods unless followed by free periods long enough to compensate. However, this research considered only the pattern of working and free days, but not shifts of different lengths and different start times.

3. Well-being measures

Based on the literature on well-being, we propose the following well-being measures: work-life balance, Fatigue and Risk indices, and deviations from the Health and Safety Executive (HSE) guidelines (Parkin and Petrovic, 2015). HSE is an organisation which provides a regulatory framework for work place health and safety in Great Britain.

3.1. Work-life balance measure

This measure serves as an indicator of the quality of the free time in an employee's roster. It is adapted from Cunningham's research work (1982) and counts the number of 2 day free weekends, free weekend days, free evenings, free blocks of at least 2 days, and free days in the given rostering period. These components are assigned weights in a subjective manner. In order to assign a single value of this metric for each employee in the given rostering period, a 'traditional' working pattern, which consists of 5 working days (Monday-Friday) with working hours 9am-5pm followed by 2 free days is used as basis. For each component, the deviation of its value from the corresponding value in a 'traditional' working pattern is calculated. Then the work-life balance measure for each employee is the average of the weighted sum of deviations of all work-life balance components. The higher value the better work-life balance measure for the given employee.

3.2. Fatigue and Risk indices

The HSE introduces two indices, Fatigue and Risk, and proposes how to calculate them. The value of Fatigue index relates to the probability of high levels of sleepiness, while Risk index is expressed in terms of the relative risk of an accident/incident occurring. Both indices are constructed from three separate components:

1. A cumulative component relates to the way in which individual duty periods or shifts are put together to form a complete schedule. The cumulative component associated with a particular shift depends on the pattern of work immediately preceding that shift.
2. A component associated with duty timing includes the effect of start time, shift length and the time of day throughout the shift.
3. A job type/breaks component relates to the content of the shift in terms of the activity being undertaken and the provision of breaks during the shift. Factors considered in this component include typical commuting time to or from work, workload, whether the job requires continuous attention, if rest breaks are taken, longest period of work before a break, and rest break after longest work period.

It is based on the Karolinska Sleepiness Scale, which ranges from 'extremely alert' to 'extremely sleepy – fighting sleep', and takes a value from the [0,100] interval (Akerstedt and Gillberg, 1990). The Fatigue index is calculated for each shift of an employee and then the average and maximum values are calculated over the whole rostering period.

3.3. Deviations from HSE guidelines

HSE investigated the effect of the shift-work on employees, and recommended the following good practice guidelines for shift-work schedule design (HSE, 2006):

- Avoid placing workers on permanent night shifts.
- If possible, offer workers a choice between permanent and rotating shift schedules.
- Where possible, adopt a forward-rotating schedule for rotating shifts rather than a backward-rotating schedule
- Either rotate shifts very quickly, e.g. every 2-3 days or slowly, e.g. every 3-4 weeks and avoid weekly/fortnightly rotating shift schedules.
- Limit shifts to a maximum of 12 hours (including overtime)
- Limit night shift or shifts where work is demanding, monotonous, dangerous and/or safety critical to 8 hours
- Consider if shifts of a variable length or flexible start/end times could offer a suitable compromise
- Avoid split shifts unless absolutely necessary to meet business needs.
- In general, limit consecutive working days to a maximum of 5-7 days and make sure there is adequate rest time between successive shifts.
- Where shifts are long (> 8 hours), for night shifts and for shifts with early morning starts, it may be better to set a limit of 2-3 consecutive shifts.
- When switching from day to night shifts or vice versa, allow workers a minimum of 2 nights' full sleep.
- Build regular free weekends into the shift schedule.
- Control overtime and shift swapping by monitoring and recording hours worked and rest periods.

For each employee, the compliance to the HSE guideline in the roster is measured, having value 1 if the corresponding guideline is followed, 0 otherwise. Our third proposed well-being measure calculates the overall compliance, where 100% is assigned to rosters which meet all the guidelines.

4. Insights obtained from using three case studies

We selected three case studies, which dealt with personnel scheduling problems of very different nature to obtain insights into the appropriateness of the definition of well-being measures and their use in the generation of schedules together with the roster performance metrics.

4.1. Shift-staff work across multiple sites

Our first case study was concerned with a large governmental organisation, which operated across a number of sites and whose staff worked shifts that cycled over several weeks. Our task was to review the effectiveness of personnel scheduling in the organisation focussing on staff welfare and the efficient deployment of resources. At each site, a different set of fixed shift patterns was used. Interviews with managers, Human Resources representatives, rostering staff and Trade Union representatives were conducted to explore their views on what constitutes a good/bad roster, and on elements of staff well-being. Staff were rather unhappy with their schedules at one site compared to other and complained on the effect that schedules had on their life and health. Our proposed well-being measures had different values among the sites and they vastly matched the views of the interviewed staff on their well-being.

4.2. Nurse rostering problems

Nurse rostering problems are known to be notoriously hard to solve due to a large number of constraints to consider. In our research, we used some of the nurse rostering instances from the Web page http://www.cs.nott.ac.uk/~psztc/NRP/, which are mostly based on real-world problems. As an illustration, we show the results obtained on an instance referred to as MER. In the MER instance, there was a large number of nurses (54); the rostering period was large (6 weeks), and that enabled us to adequately investigate the impact of introducing well-being measures. There was a great variety of shift types (12), so we could investigate the effects of fewer longer shifts versus more shorter shifts on the fatigue indicators. Cover constraints were defined for time periods rather than for shift types. Hard constraints included bounds on the required cover constraints and the minimum and maximum number of hours each nurse could work per fortnight. The soft constraints included preferred levels of the cover and requests for shifts and days off.

A rostering algorithm based on Large neighbourhood search was employed (Burke et al, 2013). The performance of the rosters was determined by the total penalty caused by the violation of soft cover constraints and shift and days-off requests. We compared the results obtained without considering well-being (referred to as baseline) and results obtained with the modified objective function that included the well-being measures with the aim to maximise the work-life balance measure, minimise maximum fatigue and risk indicators, and maximise adherence to HSE guidelines over all employees. Also, all the components in the original objective function that were related to well-being of employees were excluded, such as the constraint on maximum number of consecutive days on, maximum number of consecutive night shifts, etc. because if included they would reinforce some of the well-being measures.

The weights of the well-being components in the objective function were set based on the values of the corresponding measures obtained in the initial real-world problem that initiated our research into well-being measures in rostering, and also the values obtained in the rosters created by the original nurse rostering algorithm. The weights are given in Table 2.

Table 2. Weights assigned to well-being measures

Work life balance	Maximum fatigue	Maximum risk	HSE guidelines
1000 if score<65% 100 if 65%≤score<75% 10 if 75%≤score<85%	1000 if score>30 500 if 30≥score>25 100 if 25≥score> 20 10 if 20≥score>15	1000 if max risk>1.30 100 if 1.30≥max risk>1.20 10 if 1.20≥max risk>1.10	1000 if score≤7 100 if 7 <score≤8 10 if 8<score≤9

Table 3 presents the average and worst values of well-being measures over all nurses, the number (percentage) of nurses who had the same or better value of the corresponding well-being measure in the new roster than in the baseline, and the performance of the roster. Best results are given in bold. The new roster had all well-being measures the same or better compared to the baseline roster. For example, in the new roster, maximum fatigue was much smaller than in the baseline solution with no nurse having maximum fatigue above 42.7 compared to 53.1 in the original roster. Also, no nurse had average fatigue above 33.8 compared to 43.3 in the original one. Similarly, 83% of the nurses had the same or smaller average risk than in the baseline roster.

The improvements of all well-being measures came at the price of the performance of the roster; namely, the trade-off between the well-being measures and performance had to be made. In the new roster the penalty of the cover constraints and shift requests constraints were 1300 and 2720, respectively, while they were smaller in the baseline, 256 and 2040, respectively. In the baseline solution, 204 shift requests out of 1008 were not satisfied, compared to the new roster in which 272 requests were not satisfied. A shift request was a preference by a nurse to work a specific shift on a certain day or conversely not work at all on a certain day, and the weight assigned to the violation was 10. On examining the solutions it could be seen that some of these requests were actually in conflict with the good work-life balance measures and fatigue indicator values, which explained why they were less satisfied in the new roster. In particular, one nurse requested to work all night shifts, which she was assigned, causing a low work-life balance measure, 17.9%, and maximum fatigue of 42.7.The objective function compensated low well-being measures with a good performance measure and that led to the roster assigned to the nurse which satisfied her/his preferred night shifts. Similarly, in the new roster, the cover constraints were slightly less satisfied compared to the baseline solution. In particular, a maximum cover preference constraint was often broken. This constraint referred to a low-weighted preference to restrict the number of nurses scheduled during day shifts. In the baseline solution this was quite well satisfied. The reason for more violations in the new roster was that work-life balance and fatigue indicator encourage assignment of night shifts to as few nurses as possible. However, the nurses had minimum contracted hours to be satisfied so these night shifts were replaced in the solutions with day shifts but at the expense of breaking the low-weighted maximum day time cover requirements.

In our further experiments, with a careful change of weights of the well-being components in the objective function, and inclusion of additional constraints (e.g. a maximum number of night shifts) it was possible to improve the performance of the rostering algorithm and at the same time some well-being measures.

Table 3. Well-being measures and performance achieved in the baseline and the new rosters for MER instance

	Baseline	**Roster with well-being**
WLB Average (worst) As well as/better off (percentage)	75.5% (**27.0%**)	**86.8%** (17.9%) 38 (70%)
HSE Average (worst) As well as/better off (percentage)	61.9% (33.3%)	**83.5%** (**66.7%**) 48 (89%)
Average fatigue of employee Average (worst) As well as/better off (percentage)	17.6 (43.3)	**5.4** (**33.8**) 49 (91%)
Maximum fatigue of employee As well as/better off (percentage)	34.7 (53.1)	**9.5** (**42.7**) 46 (85%)
Average risk of employee Average (worst) As well as/better off (percentage)	0.90 (1.20)	**0.84** (**1.05**) 45 (83%)
Maximum risk of employee As well as/better off (percentage)	1.20 (2.33)	**1.03** (**1.45**) 44 (81%)
Performance	Cover constraints 256 Shift constraints 2040	Cover constraints 1300 Shift constraints 2720

When comparing rosters generated by using original objective functions with modified ones, we noticed that increasing the number of working shifts did not affect linearly the well-being measures. An appropriate distribution of working shifts was more important for employees' work-life balance measure than the number of shifts. Similarly, it was possible to increase the number of working shifts for a nurse in her/his roster without compromising her/his fatigue. Even more, it happened that in the roster with increase in the number of shifts worked compared to a baseline, the average fatigue in the roster was decreased, while only marginally increasing the maximum fatigue.

The well-being measures can be easily interpreted when staff have to work to standard rosters. However, nurses often use a self-rostering system and express their preferences for working and/or non-working particular shifts. This implies interesting questions. Is there a need to measure the work-life balance, which is highly subjective, given that staff have implicitly considered their own work-life balance when stating their preferences? Our view is that, organisations could use the well-being measures to advise staff of the implications of their preferences and to warn them if the values of the measures are particularly low. For example, in general, staff prefer longer, fewer shifts (e.g. 12 hour shifts, 4 days on, 4 days off) but this considerably worsens the Fatigue index.

4.3. Shift scheduling in a call-centre

Recent years have witnessed a large growth in the call-centre industry. Call-centres deal with phone calls (and possibly e-mails) and usually have to provide 24/7 service. This case study was concerned with a large call-centre in the UK with a target to answer 90% of calls within 20 seconds (Petrovic et al, 2018). This service had to be provided with a given number of employees. The initial consultancy work focused on the analysis of different shift patterns and their effect on roster performance using simulation modelling. The next step was to generate optimal schedules given a number of employees and shift patterns agreed with the Performance manager and Human Resource manager. We developed an optimisation model for designing shift patterns and personnel scheduling. The input to our problem was a shift pattern i.e. a sequence of shifts. Every employee worked one shift per day and shifts allocated to the employee cycled throughout the shift pattern. In our model, there were two types of decision variables: to determine a start time and duration of each shift, while shifts were subject to constraints, and to allocate to each employee a start day in a shift pattern while satisfying the constraints on the employees' contracts. The constraints on each shift included the earliest and latest start and end time, and the minimum and maximum duration. The allocated start day determined the roster for that employee for the whole rostering horizon. Two metrics were defined as performance measures for the generated roster: (1) ineffectiveness, which measured the degree to which the business requirement has not been met, i.e. there was a shortage of employees required to meet the demand predicted for the time period, and (2) inefficiency, which measured the degree to which nugatory hours have been scheduled. The objective function was defined as a weighted sum of ineffectiveness, inefficiency, Fatigue index, work-life balance, and HSE Guideline compliance index. In our previous case study, it was noted that Fatigue and Risk indices were highly positively correlated, and consequently we decided to keep only the Fatigue index. The work-life balance indicator was predefined so that smaller values were better. The objective function had to be minimised. An Evolutionary Algorithm to search for best schedules was developed using Solver add-in within Excel. Our problem instance was formulated based on the call-centre and had 20 employees, while the rostering horizon was 56 days. The generated schedules were analysed and compared with the schedules generated manually in the call-centre and schedules generated by the Evolutionary Algorithm without well-being components in the objective function. The results are presented in Table 4. The weight of ineffectiveness was larger than of other objectives because the shortage of staff had to be met via the allocation of additional staff, which was a costly solution. All schedules were 100% efficient, i.e. did not have employees unnecessarily scheduled in a time period. However, our schedule improved ineffectiveness by 20% i.e. matched better the predicted demand, improved considerably the adherence to HSE guidelines, and improved slightly the work-life balance. The Fatigue index was not improved probably due to the constraints on shifts design, which implicitly took care of fatigue.

Table 4. Results

Objective	Weight	Call centre	Evolutionary Algorith without well-being	Evolutionary Algorith witht well-being
Inefficiency	1	**0.0000**	**0.0000**	**0.0000**
Ineffectiveness	1.4	0.0395	**0.0257**	0.0315
Fatigue	1	**0.0758**	0.0921	0.0795
HSE	1	0.1167	0.1167	**0.0467**
Work-life balance	1	0.0254	0.0254	**0.0246**
Objective function		0.2733	0.2701	**0.1948**

We observed that Evolutionary Algorithm was able to generate several different schedules with similar values of the objective function, i.e. similar values of the performance and well-being components of the objective function. However, they were very different in terms of shift hours. This may serve very well in the discussion between the management and staff, who assess schedules from different aspects. It may give an opportunity to staff to have more power in shift negotiations without compromising the performance of the rosters.

5. Conclusions

The presented research is concerned with the important issue of addressing employee well-being in modelling and solving personnel scheduling problems. Based on the available literature we propose measures for well-being which should be explicitly included in personnel scheduling. Three case studies were used to evaluate the appropriateness of the proposed measures, and the effect of having well-being measures on the quality of the generated rosters. Our research shows that it is possible to improve staff well-being with appropriately constructed rosters without seriously compromising business efficiency and effectiveness.

Recently, suggestions to include well-being of employees in personnel scheduling problems and also in future rostering competitions has emerged (Gärtner et al, 2018). The researchers propose additional constraints to address employees' well-being (opposite to our approach in which explicitly defined well-being measures are included in the objective function). Especially encouraging is that these suggestions were made by practitioners with many years of experience in personnel scheduling. We believe that employee well-being measures should also be taken into account in other phases that precede and follow the generation of rosters, i.e. the planning/staffing decision on the number of employees required to cover the predicted demand and the re-scheduling activities which often happen in the real-world and involve changes to the roster to respond to unforeseen circumstances.

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