ROSTERING AT A DUTCH SECURITY FIRM

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Rostering at a Dutch Security Firm

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Abstract

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1 Introduction

Nederlandse Veiligheidsdienst BV (NVD) is the largest security firm in the Netherlands. It has about 4000 security employees working in four separate geographical regions, where they carry out security, surveillance and service tasks at about 12,000 buildings, events and special projects. The vast majority of the tasks are of a structural nature and they are mainly carried out by employees who have a fixed cyclic roster. A roster can be viewed as a sequence of work shifts, rest periods and days–off, which have to satisfy certain legal requirements. At NVD, each cyclic roster consists of tasks associated with a single subset of objects, events or projects. Besides the employees with cyclic rosters, there is a relatively small group of employees who work on a standby basis. This group carries out temporary and unforeseen tasks (such as replacement due to illness) and possibly some structural tasks (although these should preferably be assigned to employees with a cyclic roster).

Until a few years ago, all rosters were constructed by hand by a group of about 30 expert planners. They spent most of their time on the **ad hoc** rosters. The cyclic rosters typically needed much less attention since they were associated with structural tasks. Therefore, these rosters only had to be adjusted gradually over time. In 1996, however, this situation suddenly changed because of stricter labor laws that came into effect. These labor laws reflected the increased attention to ergonomic aspects of employees rosters and the desire to create more possibilities for part–time workers in response to the growing demands of the modern 24–hour global economy. Especially organizations which run a 24–hour operation, like NVD, were affected by these new labor laws. Typically, many rosters which used to satisfy all legal requirements under the old labor laws, ceased to do so.

A new Collective Labor Agreement (CLA) incorporated the new labor laws. Moreover, due to the traditionally strong position of the labor unions in the Netherlands, the CLA also contained many additional roster requirements, which were sometimes quite complicated. As a consequence, it became almost impossible for the planners to even decide whether or not a certain roster (or a modification thereof) was feasible. At this point NVD decided that the roster planning process needed to be restructured and they approached us.

We developed a decision support system for the construction of cyclic rosters. The DSS consists of four main modules, that have been developed in the order in which we will describe them. Since there was little experience at NVD with management information or decision support systems, we decided to go slowly. First, we would start with the development of some simple and useful tools to take away any existing skepticism at NVD and to build confidence in the project. Only then we would have enough support within the company to develop the more advanced modules.

2 The CLA checker

The CLA [*CAO Nederlandse Veiligheidsdienst* 1996] is a written document that, among other things, specifies in detail all the rules which any roster should satisfy with respect to its cycle length (measured in number of weeks) and the timing and duration of working hours, rest periods, (scheduled) days off and holidays. To give an impression of these rules, we have listed the most important ones in Table 1.

The CLA checker is a module which tests whether or not a given roster satisfies these rules. To illustrate that this is not always as straightforward as may seem at first sight, we give the following very simple example. One of the CLA rules states that if a roster includes a night shift, then in any period of 13 consecutive weeks the total number of working hours should not exceed 520. Now suppose that we have a roster with cycle length 3 with 35, 40 and 45 working hours in the first, second and third week of the roster, respectively, which contains at least one night shift. Since the roster is cyclic, the 13–week period starting in the first week of the roster has in total 515 $((5 \times 35) + (4 \times 40) + (4 \times 45))$ working hours. So it may seem that the rule is not violated. However, the 13–week period which starts at the third week, has in total 525 working hours. Therefore, the roster is not feasible.

The CLA checker was immediately recognized by the planners as a very useful tool. As illustrated above, because of the cyclic nature of the rosters, verifying the rules by hand is a very laborious job and practically impossible. Moreover, we found that some of the CLA rules can be interpreted in different ways. It is somewhat surprising that the Dutch Labor Inspection, the government institution responsible for verifying that companies abide by the labor laws, does not seem to have a tool similar to our CLA checker. Based on our experience (also outside of NVD), we conjecture that the vast majority of rosters used in businesses which run a 24–hour operation, do not satisfy all working hour laws. Making a tool similar to the CLA checker generally available, would not only facilitate the roster planning process, but it would also eliminate the differences of interpretation of the rules. It has even been suggested that NVD should provide the Labor Inspection with a copy of the CLA checker in order to have them test the rosters of the competition!

The CLA checker is implemented in such a way that it detects the violation of rules as early as possible, i.e., a roster may already be rejected while it is not yet completely specified. This is especially important when the checker is used as a subroutine in the roster generation, which we will discuss below. The CLA rules are implemented in a flexible way, such that modifications can easily be made in the future. For instance, the reduction of the average working week from 40 to 36 hours — currently a topic of discussion in the Netherlands — can be taken care of immediately if it comes into effect.

3 Roster generation

This module systematically generates feasible rosters with a given cycle length. The CLA checker is used to detect infeasibility of (partial) rosters as early as possible in order to keep computation times low. Although small cycle lengths are preferred, the planner may choose to consider longer cycles if smaller ones do not produce enough feasible or attractive rosters. When the cycle length is small, say no more than 2 weeks, it is possible to generate all feasible rosters in a reasonable amount of time. Since the number of feasible rosters grows exponentially with the cycle length, this is not practical anymore for longer cycles. In that case, heuristics are used to generate only a limited number of rosters.

Although the roster generation module does not include the selection of rosters, it can be used to quickly obtain an impression of the effects of changing certain rules or the cycle length. This is useful in situations such as labor negotiations between management and employees. By developing this tool, we obtained further acceptance — both from management and planners — of the idea that the DSS was actually going to take over a main part of the roster construction and selection process.

4 Roster evaluation

In order to be able to make a good choice of rosters, it was necessary to somehow measure their attractiveness. In the past, planners had been mainly concerned with trying to construct feasible rosters. Hardly any attention had been paid to the quality of the rosters that were used. An obvious criterion to take into account is the actual cost of a roster. For a given roster, this cost is straightforward to calculate. It consists of the basic wage and — depending on the roster — supplements for long or irregular working hours. Besides this economical criterion, NVD's management decided that — if possible — also ergonomic criteria should be taken into account. These criteria concern the duration and timing of shifts, rest periods and days–off and the predictability/regularity of the roster. After discussions with the management and the planners, we selected the eighteen criteria listed in Table 2. Given a roster, the evaluation module determines for each criterion a pernalty term which reflects how much the roster deviates from the ideal value of this criterion. Then an overall ergonomic penalty is calculated as a weighted sum of the individual penalty terms. The weights used in this summation can be changed by the planners if they want to give higher or less priority to certain criteria.

We should note here that feasible rosters will never have extremely high ergonomic penalties since this is prevented by the CLA rules. Furthermore, NVD management decided that the cost of a roster is always more important than its ergonomic penalty.

5 Roster selection

For each object, event or project separately, this module aims to find a collection of rosters that (in order of priority)

- cover as many structural tasks as possible,
- have the lowest total actual cost,
- have the lowest total ergonomic penalty.

The module requires as input a cycle length. Since the cycle length should preferably be as small as possible, a planner will typically start with a small one and increase it iteratively by one week until an acceptable — in the opinion of the planner — collection of rosters is found. Structural tasks which are not covered by the selected rosters will be carried out by standby employees.

Our solution approach is based on approximately solving a generalized set partitioning formulation of the problem (see Appendix). It considers only rosters which are generated by the Roster Generation module and it uses special techniques to reduce the computational burden and memory requirement of the integer programming solver.

6 Results

The main result of the DSS is that we are able to generate in a reasonable amount of time rosters which are not only feasible, but also of a high quality. The latter is reflected by their low cost and low ergonomic penalties (see Appendix for more details), but we can also make a qualitative comparison between the hand–made rosters and those generated by the DSS. The running time of the roster generation phase depends on the cycle length, but typically runs several hours on a personal computer of moderate speed. The roster evaluation module needs only minutes. The rosters by the planners would typically have very long cycles (sometimes more than the legal maximum of 12 weeks). This was a consequence of the fact that the planners tried to construct one single roster per workforce team (group of employees assigned to the same subset of objects, events or projects). The DSS typically selects several rosters with shorter cycle length which are used in parallel. To illustrate this, we consider one of the actual test cases on which we demonstrated the usefulness of our system. The input data of this relatively simple problem are given in Table 3.

For this object the planners constructed by hand the six–week roster shown in Table 4, which requires six employees (each with a different starting week). This roster is not feasible. This example forces people to work seven consecutive days without a rest period of at least 36 hours.Furthermore, note that one of the early shifts on Wednesday is open in this roster, i.e., this shift will be carried out by a standby employee.

Now consider the collection of rosters selected by our DSS presented in Table 5. We again need six employees, but each of them has a different roster with a cycle length of two weeks. Although there is again one open shift per week, this collection of rosters is to be preferred strongly over the single hand–made roster. Not only are all rosters feasible, but from an ergonomic point of view they are much more attractive. The cycle length is shorter and the workload is spread more evenly over the weeks. With such a short cycle length it is also much easier for the employees to plan social activities away from work. It is very hard to find such a collection of rosters by hand.

7 Concluding remarks

Besides the fact that the DSS is able to produce high quality rosters, its introduction in the planning process has resulted in other benefits. First of all, the whole process has become more structured and uniform. In the past, it was possible that different planners would interpret certain rules differently. Since every rule is now encoded in the CLA checker, this no longer occurs. Secondly, the planners are now able to evaluate quite fast the consequences of additional rules of measures. This may be useful, for instance, during labor negotiations. Furthermore, the planners have gained enormous insight into the planning process. This is a result of the shift of paradigm: the main focus is now on the quality and feasibility of the rosters instead of creating any roster. The realization that different members of the same workforce team may have different rosters, has led to less idle time and a reduction of total labor costs of about 2 percent.

8 Appendix

Generalized set partitioning model used in the Roster Selection module for given cycle length:

$$
\begin{aligned}
(P):\ \min z = & \sum_{j=1}^{n} c_j x_j & & \\
\text{s.t.} \quad & \sum_{j=1}^{n} a_{ij} x_j = b_i & & i = 1, \ldots, m \\
& x_j \in \{0,1\} & & j = 1, \ldots, n
\end{aligned}
$$

where

m: number of shifts in one cycle (typically, $m = 3 \times 7 \times$ cycle length in weeks)

n: number of generated feasible rosters with the given cycle length

c_j: total cost of roster j, $j = 1, 2, \ldots, n$

b_i: number of employees needed for shift i, $i = 1, 2, \ldots, m$

a_{ij} : parameter equal to 1 if shift i belongs to roster j, and equal to 0 otherwise, $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, n$

The total cost of a roster is equal to a weighted sum of its actual cost and its ergonomic penalty, where the weights are chosen such that in the minimization process the actual costs always dominate the penalty term.

Set partitioning type of models are a classical approach to roster problems (see, for instance, Baker [1976]). They have the advantage to be applicable even if the rosters have to satisfy very complicated rules, because feasibility of individual rosters is checked outside the model. The disadvantage of this approach is that the total number of feasible rosters (n) may be very large, especially for larger values of m. We have coped with this by generating only a subset of all feasible rosters if the cycle length is larger than 2 weeks (heuristic roster generation). Furthermore, we do not solve (P) directly, but we first solve its LP relaxation. Because the number of generated rosters may still be too large to do this efficiently, we start with only a small subset of these rosters. After optimizing with respect to this subset the other rosters (columns) are priced out. Favorable rosters are added to the subset and the resulting LP problem is solved. We iterate this way until the LP relaxation of (P) is solved to optimality. Let n' denote the number of rosters in the subset at termination of this procedure, then typically n' is much smaller than n. Next we solve the generalized set partitioning problem in which only these n' rosters are considered. Although this means that we solve (P) only approximately, we always find solutions with a value close to the optimal value of the LP relaxation. Hence, our solutions are provably quite good (at least with respect to the actual cost which dominate the objective coefficients c_j.)

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Berkelaar, Michel 1996, LP_SOLVE 2.0, ftp://ftp.es.ele.tue.nl (131.155.20.126) at /pub/lp_solve.

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Cycle length
Maximum cycle length: 12 weeks
Working times
Maximum working time per shift: 10 hours
Maximum working time per night shift: 9 hours
Maximum working time in any 4–week period: 200 hours
Maximum working time in any 13–week period: 585 hours
Maximum working time in any 13–week period containing a night shift: 520 hours
Maximum number of night shifts in any 13–week period: 28
Maximum number of consecutive night shifts: 7
Resting times
Minimum rest period in any 24–hour period: 11 hours,
which may be reduced to 8 hours at most once every 7×24 hours
Minimum rest period after a night shift: 14 hours,
which may be reduced to 8 hours at most once every 7×24 hours
Minimum rest period in any (9×24)–hour period: 60 hours,
unless there is a 36–hour rest period in the first 7×24 hours;
the latter may be reduced to 32 hours at most once every 5 weeks
Minimum rest period after three or more consecutive night shifts: 48 hours
Days–off
Average number of days–off per week: 2
Minimum number of weekends–off in every 4–week period: 1
Minimum number of Sundays–off in every 13–week period: 4
Minimum number of 2–day–off periods in every 4–week period: 2

Table 1: Most important CLA rules

Predictability
Cycle length (preferably small)
Number of consecutive shifts with different starting and/or ending times (preferably low)
Differences between starting and ending times of consecutive shifts (preferably small)
Workload
Average number of working hours per week (preferably 40)
Number of sequences of consecutive shifts not interrupted by a 2–days–off period (preferably low)
Average number of consecutive shifts not interrupted by a 2–days–off period (preferably 3–7)
Variability of the number of consecutive shifts not interrupted by a 2–days–off period (preferably low)
Resting time between two consecutive shifts (preferably at least 15.5 hours)
Number of working hours during the daytime (preferably 8)
Number of sequences of consecutive daytime shifts (preferably 5)
Number of working hours during the evening (preferably low))
Number of sequences of consecutive evening shifts (preferably low)
Number of working hours during the nighttime evening (preferably low))
Number of sequences of consecutive nighttime shifts (preferably low)
Number of working hours during the weekend (preferably low)
Number of sequences of consecutive weekend shifts (preferably low)

Table 2: Ergonomic criteria

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
early (6am–2pm)	1	2	2	2	2	2	1
late (2pm–10pm)	1	2	2	2	2	2	1
night (10pm–6am)	1	1	1	1	1	1	1

Table 3: Number of employees needed per shift and weekday

week	Sun	Mon	Tue	Wed	Thu	Fri	Sat	
1	e	e	e		n	n	n	
2	n			l	l	l		
3		e	e	e	e	e		
4		n	n	n			l	
5	l	l	l	l	l	l		
6		l	l		e	e	e	
open				e				

Table 4: The 6–week roster constructed by the planners

roster	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	l	e		e	e	e			l	l		l	l	l
2	e	n	n	l		l			e	e	e	e		e
3	n	l	l		l	l			e	e	e	n	n	
4		e	e	n	l		l	l	l	l	l		e	
5			e	e	e	e	e	e		n		l	l	
6		l	l	l	n	n		n	n		l	e	e	
open							n							n

Table 5: The six 2-week rosters selected by the DSS

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