Cost-efficient staffing under annualized hours

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Abstract

We study how flexibility in workforce capacity can be used to efficiently match capacity and demand. Flexibility in workforce capacity is introduced by the annualized hours regime. Annualized hours allow organizations to measure working time per year, instead of per month or per week. An additional source of flexibility is hiring employees with different contract types, like full-time, part-time, and min-max, and by hiring subcontractors.

We propose a mathematical programming formulation that incorporates annualized hours and shows to be very flexible with regard to modeling various contract types. The objective of our model is to minimize salary cost, thereby covering workforce demand, and using annualized hours. Our model is able to address various business questions regarding tactical workforce planning problems, e.g., with regard to annualized hours, subcontracting, and vacation planning. In a case study for a Dutch hospital two of these business questions are addressed, and we demonstrate that applying annualized hours potentially saves up to 5.2% in personnel wages annually.

Keywords: annualized hours, mixed-integer linear programming, staff capacity allocation, workforce capacity allocation

1 Introduction

In many industries, demand for skilled workers varies throughout the year, for example due to seasonal influences. In addition, workforce capacity varies due to, for instance, vacations, illnesses, and other scheduled and unscheduled unavailability. A good contract-mix and skill-mix, and flexibility within employee contracts like the annualized hours regime, enable organizations to efficiently

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match workforce demand and availability. Such an efficient matching of workforce demand and supply is especially important to labor-intensive industries like healthcare and professional customer services. In healthcare for instance, workforce costs amount to nearly 70% of the total costs.

In this paper we integrate two (tactical) workforce planning problems. The 'annualized hours' problem, calculates the 'optimal' distribution of available workforce capacity throughout the year. Annualized hours, as used in labor legislation in Britain Rodriguez [2003], France Grabot and Letouzey [2000], Switzerland Hertz et al. [2010], and The Netherlands van den Hurk [2007], allow organizations to measure working time per year, instead of per month or per week. This enables organizations to let employees work more hours in some periods, and less in others. In addition to annualized hours, we consider a multi-skill and multi-contract staffing problem. The 'staffing' problem is to select from a given set of candidates, with their individual skills and contracts, the 'optimal' subset of employees to cover the workforce demand. Here, we define optimal as cost-efficient. Employee costs depend on their contract type. Contract types we consider in this paper are full-time, part-time, min-max contracts, and subcontractors. Next to annualized hours, the freedom of choice of different contracts offers flexibility to efficiently cover staffing demand.

The contribution of this paper is threefold. First, we develop a model that integrates two workforce planning problems, as discussed in the previous paragraph. Second, with our model, several practical issues can be addressed, like vacation planning, skill-mix decisions, and hiring and firing policies. Third, we apply the model to a case study of the Emergency Department of the University Hospital St. Radboud Nijmegen in the Netherlands, and illustrate for some of the business questions how the model addresses them. For this case study, applying annualized hours yield a possible annual savings of 5.2% or €86000 on personnel cost within this single department of the hospital. This case study, where the annualized hours regime was not applied prior to the start of this study, also motivated this research.

The paper is structured as follows. Section 2 discusses related literature. In Section 3 we give a formal problem description, and in Section 4 we present an MILP formulation of this problem. The MILP turns out to be very flexible with regard to contract types, which we discuss in Section 4.2. In Section 5 we address the business questions that can be answered using our model, and Section 6 discusses the application of our model to the case study. Conclusions are discussed in Section 7.

2 Literature Review

In this paper we study an annualized hours problem. In various countries, annualized hours is part of labor legislation, e.g., in Britain, Germany, The Netherlands, and Switzerland. This section discusses annualized hours literature and positions our research.

In annualized hours literature workforce demand is often specified in hours of work that need to be staffed during some planning period, which also holds for our paper. However, some authors, e.g., Azmat and Widmer [2004], Azmat et al. [2004], Hung [1999a,b], specify demand in shifts that need to be staffed. Most annualized hours models in the literature consider a deterministic demand. Lusa

et al. [2008a] consider a stochastic demand, and optimize over multiple demand scenarios, each having a probability of occurrence. In this paper demand is considered to be deterministic. Furthermore, we discretize workforce demand into skills, which is also done by Corominas et al. [2002, 2005], Corominas and Pastor [2010], Grabot and Letouzey [2000], Lusa et al. [2008b].

In most annualized hours literature models, the planning horizon of one year is discretized into planning periods of weeks or days, and only a single employee contract type is considered. Multiple contract types are considered by Hertz et al. [2010], Lusa et al. [2008a,b], who distinguish full-time and part-time employees, i.e., they consider employees with different contract hours. In addition to full-time and part-time contracts, Corominas et al. [2004, 2005, 2007a,b], Corominas and Pastor [2010] also consider subcontractors. In this paper, we consider full-time contracts, part-time contracts, min-max contracts and subcontractors. In addition, we consider hiring and firing of employees, which is also done by Hertz et al. [2010].

Next to annualized hours, literature considers the related concept of Working Time Accounts (WTAs), see Corominas et al. [2012], Lusa et al. [2009], Lusa and Pastor [2011], Pastor and Olivella [2008], Pastor et al. [2010]. A Working Time Account holds a balance of the cumulative difference between an employee's contract hours and the hours worked. The objective is then to find an assignment where the WTA stays between specified boundaries. In Section 4 we outline that WTAs can be incorporated in our model by setting some parameters.

The most used solution method is used in this paper: mathematical programming. Hung [1999a,b] use special purpose algorithms for their variants of the annualized hours problem. A stochastic optimization method, known as Cross-Entropy optimization, is proposed in van der Veen et al. [2012].

The contribution of this paper is that, to our knowledge, literature does not consider modeling annualized hours in combination with multi-skill and multiple contract types, while minimizing salary cost.

3 Problem description

The problem studied in this paper combines staffing with annualized hours. Its objective is to select the least cost-expensive subset of employees that stays within the bounds implied by annualized hours, and covers demand. Demand for work is given in terms of skills and amounts of hours of work required per skill and time slot. Employees can only perform work for which they are sufficiently skilled. The cost of an employee is represented by his salary. A salary is specified in an employee's contract, which also specifies skills and working hours. We assume a salary has a fixed and a variable part. The fixed part is paid for the amount of working hours specified in the contract, and a variable part is paid for additional hours. The salary of full-time employees normally only has a fixed part, whereas subcontractors have a variable fee per hour. Section 4.2 describes the various contract types we consider.

The annualized hours regime allows organizations to measure working time per year, instead of per week or per month. The planning horizon of one year is discretized into time slots of, e.g., a week or a day. We have constraints with respect to minimum and maximum working time, for every time slot and for the complete planning horizon. In addition, we specify sub-horizons of, for

example, 4 or 13 weeks, for which we also imply constraints with respect to minimum and maximum working time. These constraints are employee specific and are determined by an employee's contract type.

We emphasize that the problem studied here is a tactical and not an operational problem. The solution to the problem studied in this paper is the number of hours that employees should work per skill and per time slot. We do not aim to construct actual shift rosters on a weekly (or daily) basis.

4 Modeling

This section discusses our modeling of the annualized hours problem. We model our problem as a Mixed-Integer Linear Program (MILP). Section 4.1 discusses the MILP, and motivates why MILP is used as modeling technique. Section 4.2 discusses how various employee contracts are modeled in the proposed MILP, and Section 4.3 discusses possible model extensions.

4.1 Mixed Integer Linear Programming

The problem studied in this paper, as discussed in Section 3, can be seen as a deterministic assignment problem with capacity constraints. The solution to this problem specifies which part of the total demand is covered by which employees (assignment), while complying with capacity constraints on the employee working hours. To solve this problem exactly we propose an MILP.

The notation used in this paper is defined as follows:

Sets, parameters:

I	set of employees, indexed by i
J	set of skills, indexed by j
$J_i \subset J$	set of skills of employee i
T	set of time slots, indexed by t
S	set of subsets of T, indexed by s
$T_s \subset T$	subset s of time slots for which working hour constraints have to be enforced
d_{jt}	demand for skill j in time slot t (in hours)
c_i^{fix}	fixed cost of employee i
c_i^{var}	variable cost of employee i
l_{it} , u_{it}	minimum, maximum working hours of employee i in time slot t
l_i^s , u_i^s	minimum, maximum total working hours of employee i in the time slots of T_s
l_i , u_i	minimum, maximum total working hours of employee i during the entire planning horizon T

Variables:

X_{ijt}	number of hours employee i works on skill j during time slot t
X_{it}	number of hours employee i works during time slot t, i.e., $X_{it} = \sum_{j \in J} X_{ijt}$
Y_i	1 if employee i is selected in the workforce, 0 if not
TC	total cost of all employees
TC^{fix}	sum of fixed cost of all employees
TC^{var}	sum of variable cost of all employees

The fixed cost, c_i^{fix}, is incurred if the employee is part of the workforce. Variable costs are incurred if the employee works more than the minimum hours that he should work, l_i, at a rate of c_i^{var} for every excess hour. Note that, using l_i here, and not l_{it}, is the basis of the annualized hours regime.

The objective function reads as follows:

$$\min TC = TC^{\text{fix}} + TC^{\text{var}}, \tag{4.1a}$$

First, we make sure demand is met in every time slot, and for every skill category:

$$\sum_{i \in I} X_{ijt} \geq d_{jt} \quad j \in J, t \in T, \tag{4.1b}$$

and that employees are only assigned to work they are skilled for:

$$X_{ijt} = 0 \quad i \in I, j \notin J_i, t \in T. \tag{4.1c}$$

Next, we define the auxiliary variable X_{it} as follows:

$$X_{it} = \sum_{j \in J} X_{ijt} \quad i \in I, t \in T. \tag{4.1d}$$

The next constraint ensures that in every time slot, the working hours of every employee are between the lower and the upper bound:

$$l_{it} Y_i \leq X_{it} \leq u_{it} Y_i \quad i \in I, t \in T. \tag{4.1e}$$

We multiply l_{it} with Y_i, since the bounds only hold if employee i is part of the workforce. Furthermore, by multiplying u_{it} with Y_i we enforce $Y_i = 0 \Rightarrow X_{it} = 0$ ($t \in T$).

For every $s \in S$, we have similar lower and upper bounds on the total working time:

$$l_i^s Y_i \leq \sum_{t \in T_s} X_{it} \leq u_i^s Y_i \quad i \in I, s \in S. \tag{4.1f}$$

Constraint (4.1f) allows us to model for example constraints on the minimum and maximum working time in 4 or 13 week periods.

The following constraint ensures that for every employee the working hours are between the lower and upper bound of the planning horizon:

$$l_i Y_i \leq \sum_{t \in T} X_{it} \leq u_i Y_i \quad i \in I. \tag{4.1g}$$

The fixed cost are defined as:

$$TC^{\text{fix}} = \sum_{i \in I} c_i^{\text{fix}} Y_i, \tag{4.1h}$$

and, the variable cost are defined as:

$$TC^{\text{var}} = \sum_{i \in I} c_i^{\text{var}} \left(\left(\sum_{t \in T} X_{it} \right) - l_i Y_i \right). \tag{4.1i}$$

Note that TC^{var} cannot be negative, due to Constraint (4.1g).

The MILP is completed with the following definition constraints:

$$X_{ijt} \geq 0 \quad i \in I, j \in J, t \in T, \tag{4.1j}$$

and:

$$Y_i \in \{0, 1\} \quad i \in I. \tag{4.1k}$$

Now, the MILP used in this paper is given by (4.1).

If we want to ensure that some subset of employees is part of the workforce, e.g., because these are employees with long-term contracts who cannot easily be fired, this can easily be added to our model. Define I^{employ} as the set of employees that must be part of the workforce, and add the following constraint to the model:

$$Y_i = 1 \quad i \in I^{\text{employ}}. \tag{4.2}$$

Note that Working Time Accounts (WTA), discussed in Section 2, can be modeled in (4.1) using appropriate values for S, l_i^s, and u_i^s.

4.2 Modeling employee contracts

The MILP model (4.1) allows to model various contract types. This section illustrates how to model various contract types, by adjusting model parameters. Section 4.2.1 considers full-time and part-time contracts, Section 4.2.2 considers min-max contracts, and Section 4.2.3 considers subcontractors. Section 4.2.4 describes how the model can be adapted so that it determines the optimal part-time factor for employees not part of I^{employ}.

4.2.1 Full-time and part-time employees

We assume that full-time and part-time employees either work in all time slots or not at all. These employees are paid a fixed employment cost c_i^{fix} for a fixed amount of hours per year. Hence, the variable hourly cost c_i^{var} equals 0. To ensure that full-time and part-time employees work exactly their annual contract hours, we set

$$l_i = u_i = \sum_{t \in T} (h_{it} - a_{it}), \tag{4.3}$$

where h_{it} denotes the employee's contract hours in time slot t, and a_{it} absences, which are implied by, e.g., vacations, education, and predicted illnesses. Note that h_{it} generally is the same in each time slot t.

4.2.2 Min-max employees

A common contract type in Dutch healthcare, is a so-called min-max contract. A min-max contract specifies per time slot the min(imum) number of hours employees are paid, and thus should work. In addition, it specifies a max(imum) number of hours the employee may be called to work. The additional hours are paid at an hourly rate of c_i^{var}. In our model, l_{it} and u_{it} equal the min and max hours, respectively. Furthermore, $l_i = \sum_{t \in T} l_{it}$, which implies that a variable cost c_i^{var} is incurred for every hour worked more than l_i.

4.2.3 Subcontractors

Subcontractors are considered to only have variable cost. Hours worked by subcontractor i are paid at an hourly rate of c_i^{var}. In practice, subcontractors can either be internal, as part of a flexpool department, or external. In general, c_i^{var} is higher for external subcontractors, and subcontractors are more expensive than full-time, part-time, and min-max employees.

4.2.4 Non-fixed part-time factor

For a full-time or part-time employee i that is not part of I^{employ} we can adapt the model to determine the optimal part-time factor. To this end, we use the same lower and upper bounds l_{it} and u_{it} as for a full-time employee, and we relax the integrality constraint on Y_i, i.e., we let $Y_i \in [0,1]$. Then we let the model determine the optimal part-time factor, Y_i, for this employee. To prohibit that Y_i attains an undesirable low value, i.e., smaller than some given fraction p_i, we add some constraints where we let the binary variable Z_i indicate whether employee i is employed ($Z_i = 1$) or not ($Z_i = 0$):

$$Z_i \geq Y_i \tag{4.4a}$$
$$Y_i \geq p_i Z_i \tag{4.4b}$$
$$Z_i \in \{0,1\}. \tag{4.4c}$$

4.3 Model extensions

Model (4.1) aims to find a cost-efficient workforce that covers demand with working hours X_{it} in time slot t between l_{it} and u_{it} for each employee i. For an employee i with $l_{it} = 35$ and $u_{it} = 45$, working hours may alternate between 35 and 45, whereas a solution where employee i works 40 hours every week might also offer a feasible, and a more preferred, solution. The following cost component may be included in objective function (4.1a) to enforce this:

$$\lambda_1 \cdot \sum_{i \in I} \sum_{t \in T} (X_{it} - l_{it})^2, \tag{4.5}$$

where λ_1 is a weight that determines the importance of this component. Note that adding this component makes model (4.1) quadratic instead of linear.

The following component may be used to steer on skill preferences of employees, where c_{ij} denotes an artificial cost of employee i working on skill j:

$$\lambda_2 \cdot \sum_{i \in I} \sum_{j \in J} \sum_{t \in T} c_{ij} X_{ijt}, \tag{4.6}$$

where λ_2 is a weight. Since full-time and part-time employees are hired for the entire year, this may imply overcapacity on an annual level. The following component may be used to distribute this overcapacity evenly over the year:

$$\lambda_3 \cdot \sum_{t \in T} \left(\sum_{i \in I} X_{it} - \sum_{j \in J} d_{jt} \right)^2, \tag{4.7}$$

where λ_3 is a weight.

If we want to prohibit that the cost components discussed in this section influence the employee selection in model (4.1), we first run model (4.1) without these cost components, add the selected employees i to I^{employ}, and then re-run the model.

5 Business questions

Our model can be used to address various business questions. It can be used to answer questions regarding contract-mix and skill-mix planning, vacation and education planning, efficiently using annualized hours, subcontracting, and it can provide rostering support. We address these in the following paragraphs. In Section 6 we present a case study that addresses some of these business questions.

Contract-mix and skill-mix planning   The model can be used to optimize the contract mix and skill mix of the workforce. To this end, one can experiment with the composition of the set I. The experiments help to address questions like: by the end of the year two employees retire, what to do? Replace them by employees with the same contracts and skills, replace them by other employees, or do not replace them at all?

Vacation and education planning   Many employees prefer to take their vacation during the summer season. The model can support planners to determine whether, given a vacation plan, there are sufficient employees to cover the (predicted) workload during vacation periods. In addition, the model supports education planning, and determines whether it is feasible to schedule a training for some employees in the same week.

Annualized hours   One of the main goals of the model is to return a feasible annualized hours plan. We discuss this in detail in our case study in Section 6.

Subcontracting vs. additional hiring   Covering the workload with contracted employees is not necessarily the most cost-efficient. Hiring subcontractors for peaks in the workload, or at times when many employees are unavailable, e.g., due to vacations, might be cheaper. We discuss this in more detail in the case study in Section 6.

Rostering support   Using annualized hours implies 'saving' hours in weeks when employee availability is high, and 'spending' hours when the opposite holds. The model outcome provides planners information in which weeks to save hours and in which weeks to spend extra hours. This information can also be used to set budgets on the number of hours employees may be scheduled during a rostering period. In addition, this information can be used to respond adequately to unexpected employee absences, e.g., illnesses. Suppose an employee calls in sick during the morning. It is then not necessarily cost-efficient to call in a contracted employee. Assigning a contracted employee to work extra in April might imply that he cannot work extra during summer. When subcontracting is cheaper in April than in the summer, and extra workforce is needed

in the summer, it may be more cost-efficient to subcontract in April and use the contracted employees in the summer. Our model supports such analyses.

6   Case study

As mentioned in the introduction, annualized hours and other forms of workforce flexibility may contribute significantly to cost reductions in labor-intensive industries like healthcare. The Emergency Department of the University Hospital St. Radboud Nijmegen, The Netherlands, was interested in exploring the impact of introducing annualized hours in their workforce deployment practice. Thus, we applied our model to a case study of the Emergency Department. We created a decision support system in an MS Excel workbook, where the model's parameter values can be specified. The MILP model (4.1) is modeled in AIMMS, which imports data from Excel. AIMMS uses CPLEX 12.2 to solve the MILP.

In Section 6.1 we describe the data and the experimental setup, and Section 6.2 presents the experimental results.

6.1   Data description and experimental setup

The department has 32 employees with a mixture of full-time and part-time contracts. In addition, the department uses subcontractors. A full-time employee has an annual salary of €60000, and the hourly tariff of subcontractors is approximately 1.7 times the hourly salary of contracted employees. The planning horizon of one year is discretized into 52 one-week time slots. Nine 8-hour and three 9-hour single-skilled shifts need to be staffed every day. Hence, 99 hours need to be staffed in a day, 693 hours in a week, and 36036 hours in 52 weeks (a year). For every employee we know his contract hours, i.e., the number of hours the employee is expected to work during a week, which we denote by h_{it}. Note that for most employees h_{it} is the same in every time slot t. Due to absenteeism, e.g., vacations, illness, and staff meetings, the hours an employee is available for work is less than his contract hours. We refer to available hours as the net availability of an employee. The net availability of employee i, in time slot t, is defined as the difference between his contract hours h_{it} and his absences a_{it}. We performed an extensive analysis to determine the expected net availability of the employees. The combined gross and the combined net availability of all employees are shown per week as the upper dashed line and the solid line in Figure 1, respectively. The lower dashed line represents the demand of 693 hours per week.

From Figure 1 we observe that in 13 of the 52 weeks demand is larger than the net availability of the employees. Hence, the net availability has a major influence on the workforce's ability to cover demand. Figure 1 illustrates that the workforce's ability to cover demand in this case study is greatly influenced by fluctuations in workforce availability. Using graphs like the one in Figure 1 helped the hospital to better understand situations of overstaffing and understaffing.

When applying annualized hours, as discussed in Section 1, one is allowed to deviate from the contracted (weekly) hours, as long as on an annual level an employee does not work more than his annual contract hours. To study the

effect of annualized hours, we introduce ρ_i, which denotes the 'annualized hours percentage', and we let l_{it} and u_{it}:

$$l_{it} = (1 - \rho_i)(h_{it} - a_{it}), \tag{6.1}$$

$$u_{it} = (1 + \rho_i)(h_{it} - a_{it}). \tag{6.2}$$

Hence, $[1 - \rho_i, 1 + \rho_i]$ specifies the bandwidth around the employee's net available hours $(h_{it} - a_{it})$ within which we allow deviations from the net available hours.

Figure 1 shows the bandwidths around the employee's net available hours for $\rho_i \equiv 0.1$ and $\rho_i \equiv 0.2$ as the shaded area and the crosshatched area, respectively.
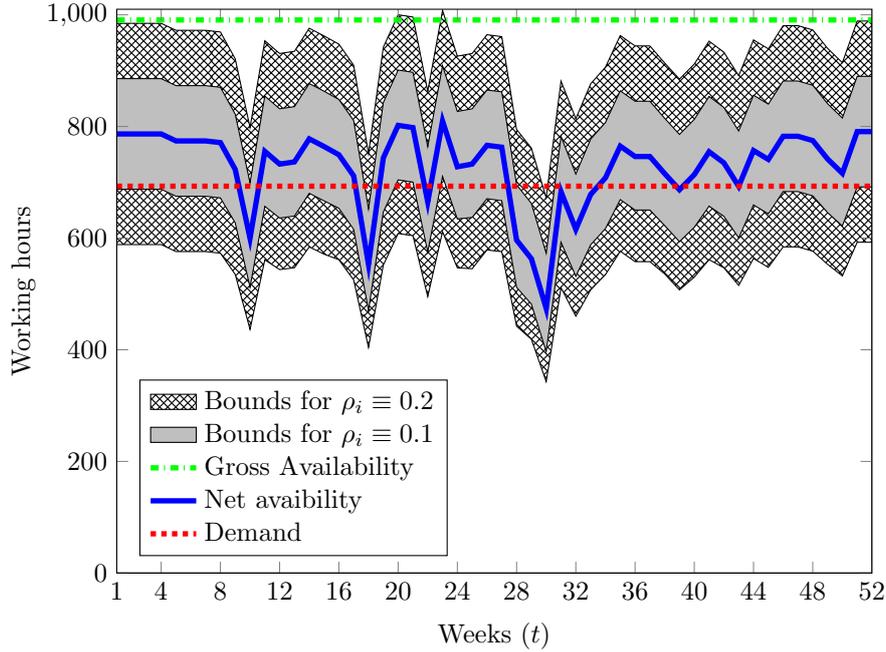

Figure 1: Demand, availability and annualized hours bounds for $\rho_i \equiv 0.1$ and $\rho_i \equiv 0.2$

In Figure 1, we observe that even for $\rho_i = 0.20$ the net available hours of the employees together cannot cover all workforce demand, since in week 18 there is still a difference of 18 hours between the workforce demand and the upper bound of the employees' net availability.

In order to analyze the effects of the salaries of full-time and part-time employees versus subcontractor tariffs, we let the salaries of full-time and part-time employees equal their annual contract hours. Thus, we let an employee have a unit 'cost' per contracted hour. Hence, for an employee with 36 contract hours per week, we set an annual 'salary' of 1872 $(= 52 \cdot 36)$. For a full-time employee we thus set $c_i^{\mathrm{fix}} = 1872$, and $c_i^{\mathrm{var}} = 0$. However, since $l_i = u_i$, see Section 4.2.1, we never incur variable cost for full-time and part-time employees. Note that, due to absences, the actual cost per productive hour of full-time and part-time employees is larger than 1. Table 1 presents an overview of the full-time and part-time contracts, the contract hours, the 'salaries' and the number of employees that have a certain contract.

Table 1: Overview of employee contract hours and salaries

Contract hrs	Employees	'Salary'
36.00	9	1872.00
32.00	10	1664.00
34.11	2	1773.72
30.32	4	1576.64
28.80	1	1497.60
26.53	1	1379.56
25.36	1	1318.72
24.63	1	1280.76
24.00	1	1248.00
16.00	2	832.00

In Table 1 we see, e.g., that 10 employees have a contract for 32 hours and a 'salary' of 1664. In total there are 32 employees, and together they have a 'salary' of 51523.

The main goal of the case study is to gain insight in the effects of annualized hours. Therefore, we vary ρ_i between 0.00 and 0.25, and analyze the effect on the selected workforce. Furthermore, we set $I^{\mathrm{employ}} = \emptyset$; so we let the model choose whom to employ. In addition, we analyze the effect the subcontractor cost has on the optimal solution. We vary the variable cost of subcontractors between 1 and 5, for every value of ρ_i. Moreover, we study the effects of ρ_i in the case we do not have subcontractors.

6.2 Experimental results

This section presents the experimental results. We do not discuss computation time in detail, since the maximum observed computation time is 10 seconds, which is negligible for this kind of analysis and decision making.

Table 2 presents results on the cost of the optimal solutions. Note that we divided the total cost (TC) of the optimal solution by 36036, which is the cost when all demand is covered by subcontractors with $c_i^{\mathrm{var}} = 1$. Note that, when $c_i^{\mathrm{var}} = 1$ the optimal solution is to only hire subcontractors, since, as noted before, the full-time and part-time employees in fact cost more than 1 per productive hour due to their absences. By dividing the total cost (TC) by 36036, it is easier to compare the various solutions.

As mentioned the current workforce has a 'salary' of 51523, which divided by 36036 equals 1.43. From Table 2 we observe that in most situations the model's solution is cheaper than employing the current workforce. If subcontractors are not used, the current workforce is only able to cover the total demand if $\rho_i = 0.25$. Moreover, without any subcontracting, annualized hours yields a possible savings of 5.2% or €86000. Furthermore, although for a subcontractor tariff of 1.7 the effect is minor, we observe that the optimal solution cost decreases for increasing ρ_i. This is to be expected, since a larger ρ_i implies larger flexibility for the full-time and part-time employees to cover the workload, and hence the dependence on (expensive) subcontractors decreases. We also observe this when looking at the total subcontractor cost in the optimal solutions, which is shown

Table 2: Total cost (TC) divided by 36036

| ρ_i | c_i^{var} subcontractors | | | | | | | | |
	1	1.5	1.7	2	2.5	3	4	5	no subcontracting
0%	1.00	1.33	1.35	1.37	1.40	1.43	1.48	1.51	no solution
5%	1.00	1.33	1.34	1.35	1.37	1.38	1.40	1.42	no solution
10%	1.00	1.33	1.34	1.35	1.36	1.36	1.37	1.38	no solution
15%	1.00	1.33	1.34	1.34	1.35	1.35	1.35	1.36	no solution
20%	1.00	1.33	1.34	1.34	1.34	1.34	1.35	1.35	no solution
25%	1.00	1.33	1.34	1.34	1.34	1.34	1.34	1.34	1.35

in Table 3.

Table 3: Total subcontractor cost for varying ρ_i and subcontractor cost

| ρ_i | c_i^{var} subcontractors | | | | | | | | |
	1	1.5	1.7	2	2.5	3	4	5	no subcontracting
0%	36036	8273	5473	4636	5795	4990	5964	5979	no solution
5%	36036	8273	1871	2202	2752	2237	2982	3489	no solution
10%	36036	8273	1857	2185	887	1064	1419	1465	no solution
15%	36036	8273	1857	578	722	397	529	426	no solution
20%	36036	8273	1857	119	149	179	239	299	no solution
25%	36036	8273	64	75	94	113	44	55	0

Additionally, from Tables 2 and 3 we observe that for small ρ_i, the dependence of the organization on the cost of subcontracting is larger. Hence, if the workforce is less flexible, the workforce cost is more sensitive to changes in subcontractor tariffs, i.e., external, non-influencable factors. Thus, using annualized hours reduces financial risk. Moreover, the results show that it is not always cost-efficient to cover all demand with contracted employees, since for most test instances subcontractors cover part of the workforce demand.

7 Conclusions and Discussion

In this paper we studied a workforce skill-mix and contract-mix planning problem that explicitly considers the annualized hours regime. We modeled this problem as an MILP. Our model includes various contract types, like full-time, part-time, min-max, and subcontractors, which are modeled in a generic and flexible way: the model only has a single, generic contract type, and contract types can be included in the problem instances by setting the correct model parameter values. The objective of our model is to cost-efficiently match workforce capacity to demand by exploiting flexibility in employee contracts and by using annualized hours.

Annualized hours allow organizations to measure working time per year instead of per week or per month, which allows organizations to deviate from employee contract hours on week level as long as they are met on annual level. We discussed how annualized hours are incorporated in our model. Furthermore,

we discussed how the model can be used to address various business questions regarding contract-mix and skill-mix planning, vacation and education planning, subcontracting policies, and how it can be used to provide rostering support.

We applied our model in a case study of the Emergency Department of the University Hospital St. Radboud Nijmegen. The MILP instances were solved in a matter of seconds. Experimental results show that the annualized hours regime decreases the dependency of the department on subcontractor tariffs, and thus reduces financial risk. In addition, without any subcontracting, annualized hours offers a possible savings of 5.2% or €86000 for this department. Moreover, results show that covering all workforce demand with contracted employees is not necessarily cost-efficient. If there is a mismatch between capacity and demand, due to peaks in demand or peaks in employee absences, assigning subcontractors to these peaks might be cheaper than contracting additional full-time or part-time employees.

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