Strategic Employee Scheduling

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Abstract. Today's highly competitive economy calls for new methods of management. Advanced practices have been proposed to manage human resources, often acclaimed to be the most important assets of any organisation. However, computer models and applications to support these methods are often not available, or not until it is much too late. This paper presents several directions for advances in strategic employee scheduling, as well as our approach for implementing these concepts.

Introduction

It is commonly observed that human resource (HR) models and applications take time to keep up with emerging management best practices (MBP). For example, the handling of homogeneous employees first published in 1950's, is still subject to research today (see [10, 14]), while scheduling employees with multiple skills have been discussed since 1980's. To accelerate this process, this paper describes in § 1, a consistent set of MBP that would make up a Strategic Employee Scheduling (SES) system. A definition of SES is given in § 2 and we compare it with existing terminology and models. We will describe our approach in implementing such a system in § 3 with some details based on Mixed Integer Programming.

In this paper, we do not consider simpler working conditions where only days-off needs to be scheduled or where the requirements are cyclic, i.e. they repeat systematically after a given period of time, typically weekly. In addition, we do not consider shift creation, which assumes cyclic requirements over a given day of the week.

1 Management Best Practices

This part describes the many concepts that managers need to consider in producing "strategic" schedules, i.e. scheduling with a strategy. Like multi-skilled staff, these concepts are not new. However, computing models and applications that handle them are only partially available today, e.g. [12].

E. K. Burke, H. Rudová (Eds.): PATAT 2006, pp. 157–166. ISBN 80-210-3726-1.

1.1 Creating, Operating and Retaining Flexible Teams

It is common knowledge that multiple skilled workers are more productive since they can change jobs to meet changing customer needs. The underlying principle is *flexibility*; i.e. teams that can *easily* and *quickly* adapt to changing market conditions; see [6]. Through our experience, *operating* a flexible team involves concepts such as:

- **Multi-term**: Annualized hours allow people to work more on certain weeks without incurring overtime. In order to avoid abuse, this flexibility is accompanied by maximal work limits at various horizons (e.g. daily, weekly, monthly or quarterly) and minimal rest duration at the day and week levels. Capacity planning becomes a necessity to avoid paying fines when these limits are violated. This important concept, similar to that of "Planning and Scheduling", is discussed further in § 1.2. Since 2000, annualized work time has become legal for many sectors of the economy in many European countries. We have been working in this area [4], [5].
- **Multi-contracts**: People may come from different walks of life with different work durations and times, e.g. students, house-wives, retired or semi-retired people. For economic reasons, different populations may be hired to cater for peak periods; their differences may be used to adapt team availability to different customer demands in the day, over the week or over a season (e.g. summer/winter season).
- **Multi-site/multi-project**: People may work on different sites or projects, according to the needs of the moment. Rather than hiring and training new personnel, it might be more efficient to have them travel across sites, e.g. during meal breaks.

In addition to *operation*, the team needs to be *created* and its members *retained*. Team creation involves the identification of key roles within the team, the assignment of available individuals to these roles and the recruitment of new staff for the missing roles. This aspect is out of the scope of the paper, being a one-time activity for which automation may not be cost-effective.

We think that *retaining* team members is an aspect that accompanies team *operation*. Other than better pay, motivation can come by work times adapted to individual needs which can change over time, better working conditions (such as security and hygiene), creation of a team spirit or through *professional mobility*. For example, highly skilled staff can act as tutors to new employees.

1.2 Capacity Planning and Scheduling and Strategic Employee Scheduling

Recently, the concept of Integrated Planning and Scheduling has been introduced, initially in the domain of autonomous systems where actions must be planned using AI-based methods and then scheduled for execution; e.g. see [13]. The constituent domains have been studied separately until recently. Both are highly combinatorial problems and their resolution methods are not dissimilar. Their integration and/or simultaneous execution within the same application are motivated by creating near-perfect schedules, to solve the problems faster, or to solve even larger ones.

We argue that AI-based planning is not always relevant in general management practices. Here, the goals are well defined in advance and do not necessarily evolve over time. In many classical scheduling areas, the concept of planning is typically based on capacity reasoning. So that given activities can take place as scheduled, it is necessary that all required resources and constituents be present in adequate number, in space and in time.

For example, in manufacturing where machines need to be scheduled (at the job-shop level), Materials Requirements Planning (MRP) software is used to organize activities so that constituent parts are available on time (at the same factory/site) and in required quantities. Resource capacity constraints are normally taken into account in Manufacturing Resource Planning (MRP2) software. Currently, such software's run independently in different departments of the company. Plans that respect capacity can be created in MRP2 that cannot be scheduled in MRP.

We see capacity planning as a natural extension to detailed scheduling, with the goal of ensuring that needed resources and materials be available in time and in quantity so that the schedule can actually be implemented. We expect the capacity planning and scheduling processes would be running step-in-step. Many of the scheduling definitions would come from capacity planning, such as team size, skill compositions, etc. When capacity planning shows that there is excessive unused capacity, it may be empowered to launch new activities.

Within the more general context of flexible teams such as that described in §1.1, we would refer to the Capacity Planning and Scheduling concept as *Strategic Employee Scheduling*, so as to avoid confusion with AI-based Planning and Scheduling.

1.3 Benefice = Revenue - Costs

We see that flexible teams seek to adapt team availability to customer requirements so that requirements can be fulfilled so that the business opportunities are not lost. The underlying concept is that the employees be fully and usefully occupied. In other words, avoid downtime. To avoid downtime, managers launch additional activities or projects. For the same fixed costs, increasing revenue would produce more benefices.

- Detect if there is enough slack to launch a new activity, while allowing for some slack to cater for unforeseen circumstances.
- Choice of a new job/mission/production to introduce/launch; this may depend on availability thresholds
- Which item to make to stock: it depends on available manpower (or what's missing and must be completed by hires), stocks of spare parts and stocking newly assembled parts.
- Compact schedules are those that have work periods (hours/days/weeks) over the shortest possible horizon. Create compact schedules at the highest possible level (e.g. quarterly), so that people can be reassigned elsewhere or on other projects.

2 Strategic Employee Scheduling: A Definition

Strategic Employee Scheduling is the process of producing detailed daily schedules for individual employees while taking the organisation's strategic goals into considerations at different time horizons (such as monthly, quarterly or yearly). This definition stems from the term “Strategic Scheduling” for example in manufacturing, where lead times for business decisions range from 3 months to several years. Strategic Scheduling is a general management methodology to consider an organization’s strategic goals and scheduling all resources to meet them. With a larger scope, it can achieve more important gains then ordinary scheduling. Models and applications have been proposed but they are *necessarily* specific to the domain or the combination of resources managed (manufacturing, transport, farm production, etc.).

In certain cases, it may be possible to combine two existing models or tools to cover the strategic terms (long and middle) and the short term. Here, a good match is essential because we need both *good strategies that can be scheduled* and *good short-term schedules that are long-sighted*. And we need to get them without having to adjust by hand the results of one to feed the other. In the following paragraphs, we offer a more precise definition in terms of objects and concepts manipulated.

2.1 Scheduling workforces, nurses or employees

Workforce scheduling is taken to be short-term assignment of tasks in time, with the attendant sequencing/precedence constraints. The people scheduled are assumed homogeneous such that individual skills are not taken into account, such as in technologically mature industries. The first work started by [7], scheduling homogeneous workers is still a research subject today [10, 14].

Employee scheduling, a term first used in [9], takes into account individual skills. Distinguishing full-time and part-time employees, each employee specifies the minimum and maximum hours per week and duration and times during the week. In the literature, some authors misuse *workforce* scheduling to refer to *employee* scheduling.

Nurse scheduling is generally more complex, producing subtly “balanced” schedules for each employee according to their individual preferences; see e.g. [1].

Some properties to be taken into account:

- Set of skills and the level of proficiency for each employee. This allows him/her to be assigned to simple tasks in a new skill, thus allowing a gradual development.
- We need to know the employees’ previous assignments so as to ensure minimum rest duration since yesterday’s work or enough rest days in the week, and to ensure that maximum work duration is not exceeded in the current month or quarter. Scheduling history can also be used to produce schedules that are balanced with respect to values of counters (such as number of night and/or weekend assignments).
- Contractual and preferred work periods and durations
- Skill and proficiency level required for each activity type.
- Per skill, the minimum assignment for each employee, thus taking into account his previous assignments. The minimum is to retain the skill qualification (for security reasons) or to upgrade it, depending on the organisation’s policy.
- Company skills to develop, employees designated for training in these skills
- Identification of activities that may be launched and the thresholds of excess manpower that justifies their launching

2.2 Planning model

The capacity planning model is an aggregated model using periods of one day, week, or month, over an annual horizon, for example. The needed amount of work (i.e. man-hours) per skill per period is forecast, either based on statistics with local corrections for events in the new horizon, or activities validated by higher management. Other inputs are employees' absence requests (i.e. summer/winter holidays). At the beginning of the year, such forecasts may be incomplete; requests formulated during the year may not be granted, especially during peak seasons.

Capacity planning consists of determining the work duration per employee per period and per skill. Other results are:

- Planning off-peak seasons where employees can take annual vacations; these assignments are nominative but employees with the same skills may exchange them
- Hiring additional hands when needs cannot be satisfied with available employees
- Launching additional activities when available manpower exceeds requirements by a given margin.

This component gives SES its strategic dimension over pure scheduling systems.

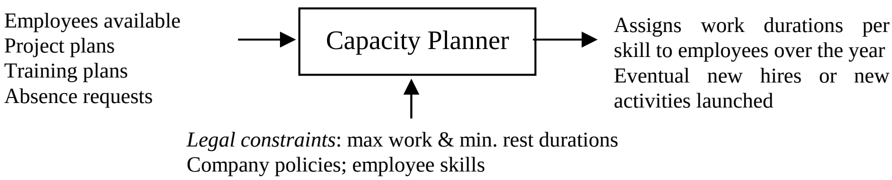

Fig. 1: Capacity Planning

2.3 Scheduling model

The scheduling model is the detailed assignment of employees to activities or skills on each day of the week. The schedule must respect the different daily/weekly constraints on work and rest duration, total work duration and total work duration per skill. There are eventually ¼ hourly requirements per day of the week, similar to those in call centers. In the distribution sector, depending on the holidays in the week, a given weekly load curve can be broken down into *standard* load curves per day.

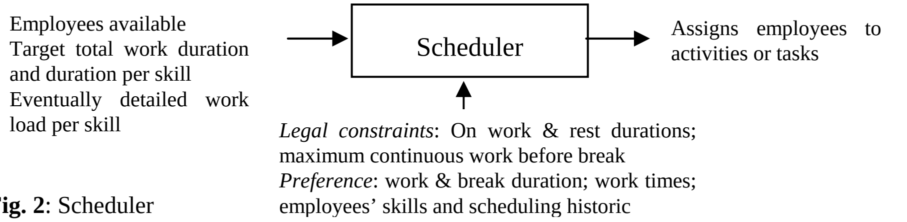

Fig. 2: Scheduler

The scheduler could also be used to verify if various parts of the annual capacity plan can be scheduled. Compared to conventional schedulers, it handles multi-skills and performance levels. It would also take into consideration some planning constraints such as slack thresholds: if exceeded, it would abort and request the planner to activate additional tasks (which invalidates the current schedule anyway).

It is the presence of the planning model and its integration to the scheduling model that transforms the whole into an SES. The integration may be at the model level, where the linear equations of both levels coexist.

3 Our Approach to Strategic Employee Scheduling

In this section, we describe our approach to solving the SES problem as described in § 2. We propose two models for (a) capacity planning and (b) detailed scheduling. We solve a capacity planning problem at the annual horizon with weekly periods. Here the work hours of each employee are distributed so as to meet the forecasted demand, i.e. the number of hours of expected work NW(s, w) per skill s and per week w. The total working duration per week is bounded legally. The average working duration per week over 3 months and the total annual working duration are also bounded. Employees' requests for summer / winter holidays may be integrated within the plan at this stage. With the weekly skill distribution known, we attempt to produce a detailed schedule for all days in the current weeks that is compatible with labor constraints such as maximum work and minimum rest durations per day and per week. If such a schedule is unfeasible, we recalculate the annual plan; in particular, we check the plan for the following weeks and eventually recalculate the detailed schedule for some weeks (if they are already calculated).

In the following, we first detail the capacity planning step. The detailed scheduling step can be formulated as described in § 3.2. The set of employees is denoted **Employees**; the skills of employee e is denoted **Skills**(e); the periods in day d (or week w) is noted **Periods**(d) or **Periods**(w). We assume that each skill implies the site at which the skill can be exercised.

The proficiency level of a skill is factored out of the mathematical model. Each combination of (Skill, Site, and proficiency level) is mapped into a different skill, e.g. s1 = (s°, Paris, high), s2 = (s°, Paris, medium), s3 = (s°, Paris, low). An employee expert in s° will have the three mapped skills and a trainee will have only s3.

3.1 Capacity planning in SES

The capacity planning problem uses the integer variables Y(e, s, w) representing the number of hours worked by employee e in a skill s over week w. The total work duration in the week w is given by (1). WD is a semi-continuous variable, bounded by the minimum and maximum contractual weekly work duration: $CW_{Min}(e)$ and $CW_{Max}(e)$. It is null if employee e takes weekly holidays.

$$WD(e, w) = \sum_{s \in \mathbf{Skills(e)}} Y(e, s, w), \forall e, \forall w. \tag{1}$$
$$CW_{Min}(e) \le WD(e, w) \le CW_{Max}(e).$$

The legal annual work limit CA_{Max} (e) is assured by

$$\sum_{w = \mathbf{1 \ldots 52}} WD(e, w) \le CA_{Max}(e), \forall e. \qquad \mathbf{(2)}$$

Another legal limit is that the average weekly hours over all sliding horizons of CH=16 consecutive weeks must not exceed CH_{Max}:

$$\sum_{w = \mathbf{0 \ldots CH-1}} W(e, a + w) \le CH_{Max}/CH, \forall e, \forall a = 1 \ldots 52 - CH \qquad \mathbf{(3)}$$

The requirements constraint is given by NW(s, w) for skill s in week w:

$$\sum_{e \in \mathbf{Employees}} Y(e, s, w) \ge NW(s, w), \forall s, \forall w. \qquad \mathbf{(4)}$$

Creation of compact plans at the week level

The logical conditions that imply compact schedules (§ 1.3) is that when there is no work on weeks w and w+2, week w+1 must be off as well:

If WD(e, w) > 0 and WD(e, w+2) > 0 **Then** WD(e, w+1) > 0

This condition may be translated into linear equations. We use binary variables Bi to hold when the WD variables > 0; M designates the bound $CW_{Max}(e)$

If WD(e, w) > 0 **Then** X0 = 1 $\quad WD(e, w) \le M \times B0; M \times B0 - M \le WD(e, w);$

If WD(e, w+2)>0 **Then** X2= 1 $WD(e, w+2) \le M \times B0; M \times B0 - M \le WD(e, w+2);$

Next, we take the product of the variables B0 and B2 and link them to WD(e, w+1):

$B1 \le B2; B1 \le B0; B1 - 1 + B0 \le B1; B1 \le WD(e, w+1)$

Hence, over 52 weeks, we add 400 equations and 52 Boolean variables per employee. When single off weeks are requested by the employee, we have to avoid posting the corresponding equations.

New hires

Some dummy employees would be included during capacity planning. The lower bounds on total work duration per week would lead to employees either partially or completely unemployed over the year, which means that they can be removed. If the work load exceeds available work capacity of dummy and real employees, the linear relaxation of the system of equations would quickly prove to be infeasible.

Launching new activities

Projects that last more than a week, with different skill requirements during each week of the project life, need to be scheduled, i.e. assign them in time subject to resource capacity limits. We expect such projects to be decided and scheduled very early in the process and taken in account by NW(s, w). SES needs only to consider launching projects or activities that can be completed within the week, given enough manpower.

To do so, capacity planning is activated without extra employees. At week w, the selection of projects to launch is a classical project selection problem with the 0-1 variables Project(j, w) = 1 if project j is selected for the week w, 0 otherwise. Given a set of **Projects**, where each j requires a(j, s) hours of skill s, the basic requirement is

$$\sum_{j \in \mathbf{Projects}} a(j, s) \times Project(j, w) \le NW(s, w) - \sum_{e \in \mathbf{Employees}} Y(e, s, w), \forall s, w$$

The objective function to maximize is $\sum_{j \in \textbf{Projects}} c(j) \times \text{Project}(j, w)$, c(j) being the profit of the project j. These projects are selected and added to NW(s, w) before moving onto the scheduling step.

Hence, handling new activities is not a direct MIP problem but requires updating the weekly requirements, may require user interaction to finalize the selected projects.

3.2 Scheduling with 0-1 variables and patterns

The scheduling problem of day d uses the 0-1 variables: X (e, s, p) takes the value 1 if employee e is assigned to work with skill s at the period $p \in$ Periods(d), 0 otherwise.

$$\sum_{s \in \textbf{Skills(e)}} X(e, s, p) \le 1, \forall e, \forall p. \quad \textbf{(5)}$$

The needs in skill s of each daily period p, designated by ND(s, p), are covered if

$$\sum_{e \in \textbf{Employees}} X(e, s, p) \ge ND(s, p), \forall s, \forall p. \quad \textbf{(6)}$$

It is straight forward to link the variables X to those in capacity planning. If we define the auxiliary binary variables $U(e, p) = \sum_{s \in \textbf{Skills (e)}} X(e, s, p)$. They take the value 1 if e is working on period p and 0 otherwise.

$$WD(e, w) = \sum_{p \in \textbf{Periods(w)}} U(e, p), \forall e, \forall w \quad \textbf{(7)}$$

$$Y(e, s, w) = \sum_{p \in \textbf{Periods(w)}} X(e, s, p), \forall e, \forall s, \forall w. \quad \textbf{(8)}$$

At this stage the model can be used to produce schedules that cover stated requirements, but the employees may be required to work for periods scattered here and there and resting in between. Labor law stipulates that employees are paid a minimum duration of H_{Min} periods on any day. To produce compact and cost-effective schedules, we use patterns, similar to that proposed in [8].

Patterns on a daily horizon

A pattern n in the set of **Patterns** is defined by the subset of periods that it covers, i.e. v(n, p) = 1 if pattern n covers period p. Valid patterns are those that require employees to work on compact schedules, with adequate meal/short breaks. We define a supplementary decision variable X'(e, n) taking the value 1 when employee e is assigned to pattern n; the following equations hold:

$$\sum_{n \in \textbf{Patterns}} X'(e, n) = 1, \forall e. \quad \textbf{(9)}$$

$$\sum_{s \in \textbf{Skills(e)}} X(e, s, p) \le \sum_{n \in \textbf{Patterns}} X'(e, n)\, v(n, p), \forall e, \forall p. \quad \textbf{(10)}$$

Equation (9) stipulates that each employee is assigned to one and only one pattern. For a given employee e and period p, if e is assigned to pattern n which covers p, then $\sum_{s \in \textbf{Skills(e)}} X(e, s, p) \le 1$ and e may be assigned to a skill s or to rest. If pattern n does not cover period p, the sum is 0 and $\sum_{s \in \textbf{Skills(e)}} X(e, s, p) \le 0$, i.e. e must be at rest.

Designating the cost of assigning employee e to pattern n by c(e, n), the total cost is

$$\sum_{e \in \textbf{Employees}} \sum_{n \in \textbf{Patterns}} X'(e, n)\, c(e, n) \qquad \textbf{(11)}$$

Patterns render the schedule less flexible in assigning individual periods, although they interpret regulations such as minimum and maximum work durations (at the daily horizon in this case), acceptable break windows, etc. It allows valid solutions to be found rapidly but there may be over capacity on some periods. Without the equations (9) to (11), the model is limited to small instances with less than 15 employees, 3 skills and 44 periods. The implicit short-term scheduling method can also produce solutions quickly, see [11], [3], [5], etc. It reasons on the number of assignment changes instead of the number of employees on the job: the resulting model cannot be directly related to the capacity planning model.

Patterns on a weekly horizon

We need to handle the sequence of patterns on successive days so as to respect minimal rest between them. For example, an employee finishing at 11 pm would not take the morning shift starting at 7 am the following day. Instead of the variable n, we have $n_d \in$ **Patterns**, where $d \in \{1, 7\}$ in the equations (9) to (11)**.**

Define a weekly pattern m by the Boolean variable u(m, n, d) = 1 if and only if n is the d^{th} daily pattern of the valid weekly pattern m. Each employee is assigned to one and only one weekly pattern per week.

$$\sum_{m \in \textbf{Weekly Patterns}} X''(e, m) = 1, \forall e. \qquad \textbf{(12)}$$

$$X'(e, n_d) = \sum_{m \in \textbf{W. Patterns}} X''(e, m)\, u(m, n, d), \forall e, \forall n, \forall d \in \{1, 7\}. \qquad \textbf{(13)}$$

To handle the weekly horizon, we replace $X'(e, n_d)$ by $X'(e, n, d)$.

4 Conclusions

In this paper, we discussed the concept of Strategic Employee Scheduling, its constituents and one possible implementation. Scheduling employees with a strategy: this is different from existing concepts in human resource management by the ability to handle extra-scheduling features such as team sizing, launching extra activities, or taking into account considerations outside the usual scheduling horizon. We aim to convince researchers that the world of human resource management is very rich and there are many aspects that must be taken into account, instead of the homogeneous resources first discussed 50 years ago.

To implement the planning and scheduling components, we proposed MIP models for capacity planning and detailed scheduling that can be directly related to each other (i.e. (8)). Building onto the pattern model of [8] published in April 2006, we see that patterns are well suited to planning at multiple horizons, since they implement sets of assignments of one level which may be manipulated at the next. We are currently in the process of validating the system and no computation results are available. It is not our aim to propose THE model for solving Strategic Employee Scheduling; we encourage researchers to look into the MBP described in § 1 and propose their models.

Acknowledgement: We wish to thank Dr. Troy Daniels of BaeSystems for helping us to translate our first logical conditions into linear equations, at the Lp_Solve forum at http://groups.yahoo.com/group/lp_solve/.

We are also thankful to the reviewers who proposed many changes to improve this paper, and the second part was subsequently rewritten.

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