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Impact of flexible work contracts and multi-skilled agents on a multi-objective workforce planning problem

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This article studies the impact of flexible work contracts and multi-skilled agents on a multi-objective workforce planning problem. Each agent has a work contract with a weekly and daily work capacity. The company has to create a planning for its agents to fulfil the customers' demands. When assigning agents to specific demands, three different objectives have to be attained, including minimizing the travel costs between agents' home and their workplace, and maximizing agents' satisfaction related to the workload balance between them, and to their preferences for certain working periods. In the context of the evolution of the demands over time, the company has to introduce different levers to increase the level of workforce flexibility. Flexible work contracts and multiple skills are the two levers that are focused on here. The mixed integer linear programming method is used to model and solve the problem. Numerical experiments with real data provided by a Brazilian company show the positive impact of these two levers on the feasibility of problem solving and on the quality of the solutions obtained. Different managerial recommendations based on these results are proposed to companies to help improve their strategy for workforce development.

Keywords: workforce assignment; multi-objective optimization; mixed integer linear programming; preference satisfaction; workload balance; cost minimization

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1. Introduction

This article studies the impact of flexible work contracts and multi-skilled agents on a multi-objective workforce planning problem. The problem under study is inspired by the case of a Brazilian subcontracting company that provides cleaning, concierge, and surveillance services to businesses such as banks, hospitals, and shopping centres. The company is currently working only with clients whose requirements are stable over time. However, more and more requests from its current clients and potential new clients are for variable services. The company therefore wants to know whether its current workforce is able to fulfil variable demands and, if not, what organisational levers should be considered to increase its workforce flexibility.

Flexible work contracts are commonly used as a lever to increase the flexibility of a workforce (Bard 2004; Hertz, Lahrichi, and Widmer 2010; Stolletz and Zamorano 2014). (Stolletz and Zamorano 2014) study a tour-scheduling problem for check-in counters at airports in which they consider flexible contracts. These authors assume that agents of flexible contracts have both shift length and shift-start flexibility. (Bard 2004) considers part-time flexible contracts, which can have different start times and shift lengths for every assigned day. In the present study, a flexible contract is defined with variable start and end times per day and a variable number of workdays per week. In reality, the percentage of flexible contracts in comparison to stable contracts may be limited by labour regulations. Moreover, because of the variability in work time per week, the agents who have flexible contracts are usually less loyal to the company than those with more stable contracts. Therefore, having a reasonable proportion of agents with flexible contracts can be considered to increase the level of workforce flexibility, while complying with regulations, and ensuring long-term workforce stability.

Besides introducing flexible contracts, the other two common levers to increase the level of workforce flexibility are using multi-skilled agents, and having the agents work extra hours. Multi-skilled agents are those who have some secondary skills in addition to their main skills (Yuan, Liu, and Jiang 2015). These secondary skills can be their personal skills available before being recruited, or those that they learned during the training process after recruitment. In many companies, only one skill type is considered for agents even if they have several different skill types. Moreover, the training process focuses on improving only agents' main skill, not their secondary skills. The opportunity to exploit agents' secondary skills has usually been ignored. In the literature, multi-skilled agents have generally proved effective in improving the workforce flexibility (Attia, Duquenne, and Le-Lann 2014; Chen et al. 2017; Pastor and Olivella 2008; Rönnerberg and Larsson 2010; Stolletz and Zamorano 2014). (Stolletz and Zamorano 2014) study a multi-skilled – called 'generalist' by the authors – workforce planning problem. They found that 'additional flexibility can be gained by increasing the proportion of generalist agents in the workforce'. However, they suggest to be careful when considering 'generalist' agents; an appropriate percentage of these agents should be considered, both to make full use of their skills and avoid a higher workforce cost in case agents' salary depends on the number of their qualifications.

Using the agents' extra hours is also often considered in the literature (Bard 2004; Pastor and Olivella 2008; Stolletz and Zamorano 2014). Two common ways to consider these extra hours are traditional overtime (Chu 2007; Constantino et al. 2011; Dias et al. 2003), and work time modulation under annualized hours (Hertz, Lahrichi, and Widmer 2010; Hung 1999; Pastor and Olivella 2008). With traditional overtime, each agent is assumed to be able to work a maximum number of extra hours every day, week, and month. This approach is simple and easy to manage but it does not give enough workforce

flexibility in cases where the demand fluctuates significantly between planning horizons. With the second approach, a modulation counter is used to measure the difference between the real and the contract work time of each agent on a planning horizon. This counter is cumulated from one horizon to the next. The advantage of this approach is that, for each planning horizon, it allows all the agents to work a certain number of hours more or less than their contract work times, depending on the real demand of that horizon. However, a drawback is that some agents may work too much on one horizon and little on another one when the demand varies widely. This both reduces agents' satisfaction and upsets the workload balance between them. In order to solve this problem, minimizing the difference of the modulation counters between the agents is set as an objective.

Demand variability is usually associated with a cost increase for the company (Bhatnagar, Saddikutti, and Rajgopalan 2007). In the service-to-business domain, reducing service costs is important for companies to survive. Agents' salaries are generally identical between companies in the same service industry and the same region. Therefore, they do not attract much attention. By contrast, travel costs are a very interesting topic. The clients are usually located in the city centres while most of the agents live in the suburbs. Companies have to refund their agents for each work trip they take (usually by public transport). These costs are huge because the number of agents and the service coverage area are generally large. Together with the reduction of the travel costs, the company wants to increase the satisfaction of its agents to ensure that they do not go over to the competitors. As mentioned above, considering work time modulation under annualized hours, the agents' real work time can be quite different from their contract work time, and this can affect their satisfaction. Together with travel cost minimization, minimizing this difference is considered as a second criterion. Finally, when using flexible work contracts, agents may have to work for different periods every day. The agents can, therefore, be assigned to the periods that do not suit them very well, which also affects their satisfaction. Therefore, in addition to the two criteria above, the third criterion is maximizing agents' preferences for working periods. (Naderi and Kilic 2016) consider two objectives, minimizing travel costs, and maximizing agents' satisfaction associated with their workload balance. (Braekers et al. 2016; Örmeci, Salman, and Yücel 2014) consider minimizing travel costs, and maximizing agents' satisfaction related to their preferences for working periods. (Borsani et al. 2006) consider minimizing total assignment costs, and maximizing agents' satisfaction associated with both workload balance and preferences for working periods. However, they consider only multi-skilled agents, not flexible contracts to improve workforce planning. In Table 1, the current study is positioned by comparing the problem characteristics considered to those found in the literature. Among the latter, the characteristics considered by (Rönnerberg and Larsson 2010) are quite close. First, they consider a tour-planning problem that consists of both shift and days-off planning. Then, the same two levers are considered to increase workforce flexibility: multi-skilled agents, and full-time and part-time contracts with a flexible work schedule. After that, the same annualized-work-hour approach is used to control agents' weekly variable work time. However, in terms of performance criteria, they consider the workload balance and the assignment costs (or workforce costs) related to agents' salaries, whereas three performance indicators are considered in this paper: the workload balance (MC), the travel costs (TC), and the agents' preference for and satisfaction with certain work periods (PR).

Table 1. Research positioning

Article	Shift / days-off planning	Multi-skilled agents	Full-time contracts with a flexible schedule	Part-time contracts with a flexible schedule	Annualized work hours	Performance criteria			
						TC	MC	PR	AC
Attia et al., 2014	Days-off	X	X		X				X
Bard, 2004	Both		X	X	X			X	X
Braekers et al., 2016	Both	X		X		X		X	X
Cavada, Cortés, and Rey, 2020	Both		X						X
Hertz, Lahrichi, and Widmer 2010	Both		X	X	X		X		X
Kiermaier, Frey and Bard, 2020	Both	X	X						X
Parisio and Jones, 2015	Both	X	X	X				X	X
Pastor and Olivella, 2008	Both		X	X	X			X	X
Porto et al., 2019	Both	X	X	X					X
Rönnerberg and Larsson, 2010	Both	X	X	X	X		X		X
Stolletz and Zamorano, 2014	Both	X	X	X					X
This study	Both	X	X	X	X	X	X	X	

TC: travel costs, MC: workload balance, PR: agent satisfaction, AC: assignment costs

Section 2 presents the characterization of the problem. Section 3 proposes a mixed-integer linear programming method (MILP) for solving the problem. In Section 4, numerical experiments with real data are performed to investigate the two levers proposed i.e. flexible contracts and multi-skilled agents. The consideration of these levers is compared to other situations where work contracts are more rigid and/or agents are only mono-skilled. Finally, Section 5 provides some conclusions and perspectives for future research.

2. Problem description

This section starts with the description of the characteristics of the planning horizon (Section 2.1). It is then followed by the presentation of the characteristics of the four objects that describe the problem: the clients, the demands (tasks), the agents with stable and flexible contracts and possibly multiple skills, and their travel routes (Section 2.2).

2.1. Planning horizon

When the demands are variable, the planning horizon should be considered short. In this paper, a one-week planning horizon of seven workdays is considered. Each workday on the planning horizon consists of 24 hours, starts at 4:00 a.m., and is divided into 6 periods of 4 hours each (Figure 1). The task duration is assumed to be a multiple of 4 hours that

corresponds to an integer number of periods. Any required task has to start and end within a day; inter-day tasks are not considered. Agents performing tasks of at least 8 hours can take a flexible break of 30 minutes, depending on their workload. The break time is, therefore, included in the task duration and will not be discussed further in the paper.



Figure 1. Periods of a workday on the planning horizon

Agents' availability on the current planning horizon is considered independent of their activities on the previous horizon. The only relationship is the work time cumulated from one horizon to the next and measured by the modulation counter (see Section 2.2.3).

2.2. Meta-model

This section characterizes the problem through four objects that are presented in the meta-model in Figure 2: clients, tasks, agents, and travel routes.

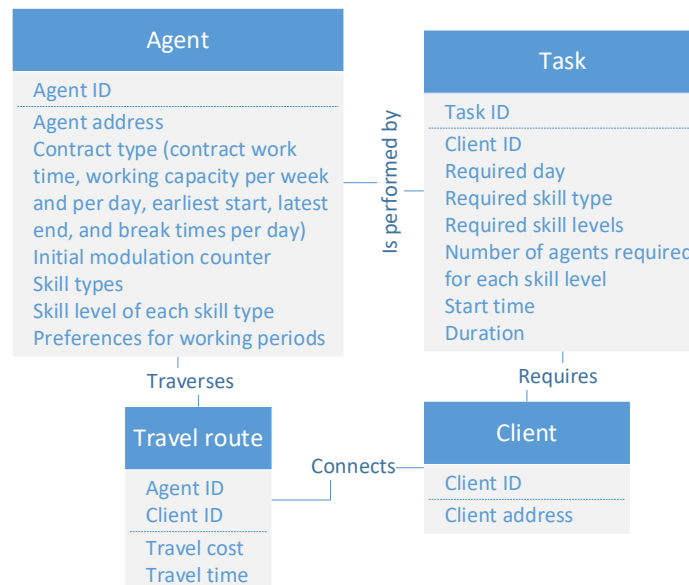


Figure 2. Meta-model of the workforce planning problem

2.2.1. Client

The subcontracting company provides services to its clients. Each client is identified by a client ID and has a unique address where the service is performed.

2.2.2. Task

This object models the demand of clients. Required services are divided into tasks to

assign to agents. Each task is represented by a task ID and a day on which it is required. It has a start time and a duration. Each task has a task type that corresponds to an agent skill type, and requires a certain number of agents of each skill level. Further explanations for the required skill type, the required skill levels, and the number of agents required for each skill level are given below.

Required skill type: A required skill type is a combination of a service type and a workplace type. For example, if the service type is cleaning and the workplace type is a hospital, the required skill type will be hospital cleaning.

Required skill levels: For each skill type, different skill levels are required. Generally, three basic skill levels are considered in the service-to-business domain: supervisor (level 2), leader (level 1), and normal worker (level 0). A group of several agents working on the same task should have a leader to manage it, and several groups of agents assigned to the same task need a supervisor.

Number of agents required for each skill level: this is the number of agents of each skill level working in parallel to perform the task, between its start and end times.

2.2.3. Agent

Tasks are performed by agents. Agents have a home address from which they leave for work, one or many skill types with a skill level for each type, and preferences for different working periods of the day. A contract type defines their contract work time per week, the earliest start, latest end, and break times per day. For each agent, an initial modulation counter indicates the work time cumulated from the previous planning horizon. Further explanations of the contract type, initial modulation counter, skill type and skill level for each skill type are given below:

Contract type: The first three contracts (5x2, 6x1, and 5x1) are non-shift contracts with daily work time that is the same every day (8h). The last three contracts (12x36, 8x24, and 4x20) are shift contracts with daily work time that can differ between days of the week.

- **Contract 5x2:** During a week, agents of this contract type have five consecutive workdays and then two consecutive days off. Their weekly work time is 40 hours (see Table 2, row 2).
- **Contract 6x1:** During a week, agents of this contract type have six consecutive workdays and 1 day off. Their weekly work time is 48 hours (see Table 2, row 3).
- **Contract 5x1:** Agents of this contract type have five consecutive workdays and 1 day off for a period of 6 consecutive days. Their weekly work time is 40 or 48 hours, depending on their first workday (see Table 2, row 4).
- **Contract 12x36:** Each agent of this contract type has a work cycle of 48 hours including a work shift of 12 consecutive hours and a break of 36 consecutive hours directly afterwards. This means that these agents work 12 hours for any period of two consecutive days. Therefore, during a week, they can work 36 or 48 hours, depending on their first workday of the week (see Table 2, row 5).
- **Contract 8x24:** An agent of this contract type has a work cycle of 32 hours, including a work shift of eight consecutive hours and a break of 24 consecutive hours directly afterwards. Therefore, depending on the first workday of the week, they can work 40 or 48 hours a week (see Table 2, row 6).

- **Contract 4x20:** this contract is a flexible part-time contract of 28 hours a week. Agents with this contract are allowed to work between zero and three periods (12 hours) a day, and a minimum of 24 hours and a maximum of 32 hours per week. However, in order to avoid multiple trips per day, working periods of a day have to be consecutive. Moreover, a minimum break time is set between two consecutive shifts to ensure the work capacity of these agents (see Table 2, row 7). As an agent generally needs about 8h of sleep per day and an amount of time to travel between their home and their workplace, a duration of 12 hours is set for this minimum break time.

Table 2. Characteristics of the four contract types existing at the Brazilian company and the two new proposed ones (8x24 and 4x20)

Contract type	Work time /period	Break time /period	Possible work time /week	Possible working periods	Contract work time /week	Estimated travel time /week
5x2 (NS)	5 consecutive days/week	2 days /week	40h	1-2, 2-3, 3-4, 4-5, 5-6	40h	15h
6x1 (NS)	6 consecutive days/week	1 day /week	48h	1-2, 2-3, 3-4, 4-5, 5-6	48h	18h
5x1 (NS)	5 consecutive days/6 days	1 day /6 days	40h or 48h	1-2, 2-3, 3-4, 4-5, 5-6	46.7h	17.5h
12x36 (S)	12h/48h	36h/48h	36h or 48h	1-3, 2-4, 3-5, 4-6	42h	10.5h
8x24 (S)	8h/32h	24h/32h	40h or 48h	1-2, 2-3, 3-4, 4-5, 5-6	42h	15.75h
4x20 (S)	0, 4h, 8h or 12h / day	At least 12h	24h-32h	1, 2, 3, 4, 5, 6	28h	10.5h

S: Shift, NS: non-shift

Of these six contracts, the three non-shift contracts and the 12x36 shift contract already exist at the Brazilian company, while the 8x24 and 4x20 are the two new flexible contracts considered as a lever to increase the level of workforce flexibility. These two contracts, especially the 4x20, have very flexible start and end times per day and a flexible number of workdays per week that allow them to stand alone or to be combined with other contracts to facilitate the completion of the tasks.

Initial modulation counter: Because agents' real work time (including their real travel time) can be different from their contract work time (including estimated travel time), a modulation counter is used to measure this difference. The value of the modulation counter at the end of the previous planning horizon is the initial modulation counter of the current horizon. This counter can be negative, positive or zero.

Skill types: are types of skills that an agent has to perform tasks. Each agent can have several skill types. Each agent skill type corresponds to a skill type required by tasks.

Skill level of each skill type: For each skill type, an agent has a skill level. Supervisor, leader, and normal worker are the three most common skill levels used in subcontracting service companies. The agents' skill level for a workplace type depends on their main workplace type. For example, as a leader in a hospital, the agent can work as a leader in a shop without difficulty. However, an agent working in a shop, restaurant or factory, may find it difficult to work in a hospital.

Preferences for working periods: Because shift agents (12x36, 8x24 and 4x20) can have different daily start and end times over the week depending on the tasks they perform, they are assumed not to have a special preference for working periods. This value is therefore assumed to be zero for all of these agents. Non-shift agents, on the contrary, who depend on their daily routine, may prefer some working periods to others. Agents can be categorized into three groups according to their preferences (see Table 3). The first group corresponds to those who prefer daylight working periods (periods 2: 8 am- 12 noon and 3: 12 noon - 4 pm). The preference value is +1 for these periods. Working for periods 1 (4 am- 8 am) and 4 (4 pm- 8 pm) does not really make them happy but they are not either unsatisfied. The preference value is 0 for these two periods. By contrast, working for periods 5 (8 pm- midnight) or 6 (midnight - 4 am) makes them really unhappy. The preference value is -1 for these periods. Similarly, the second and third categories correspond to agents who prefer working in the late afternoon until late evening (periods 4 and 5), and late evening until early morning (period 6 and period 1 of the following day), respectively.

Table 3. Three agent groups' preferences for different working periods

Period Agent group	1	2	3	4	5	6
1	0	+1	+1	0	-1	-1
2	-1	0	+1	+1	0	-1
3	0	-1	-1	0	+1	+1

+1: like, 0: neutral, -1: dislike

2.2.4. Travel route

Agents have to travel the routes that connect their homes and workplaces. This involves travel time and induces a travel cost. The travel times and costs are assumed to be the same for home-to-work and work-to-home trips. In order to ensure the balance of travel times between agents, each agent is supposed to spend, on average, a fixed amount of travel time per work trip, for example, 3 hours. Because each work contract has a different number of work trips per week, the estimated travel time per week of each contract is therefore different (see Table 2, column 7). This estimated travel time added to contract work time represents the total estimated work time of an agent.

3. Problem modelling

Given a list of tasks required by clients and a number of available agents, the company has to decide which agent will perform which task. Three objectives have to be attained, which include minimizing the total travel costs between the agents' homes and their workplaces, and maximizing agents' satisfaction related to the workload balance between

them, and to their preferences for working periods. Additionally, different constraints have to be met, including the on-time task delivery requirement, the number of agents of each skill type and skill level required by tasks, and the start, break and end times of each work contract imposed by labour law. A mathematical modelling and solving approach like MILP appears to be a reasonable choice to investigate the problem characteristics rather than approximation methods. This approach is found to be efficient when the problem is not too big and a short calculation time is not required. These two conditions are met in the current study. First, the numbers of clients, tasks, and agents of a typical district are usually not too large (see Section 4.1). Second, the company can take as long as one week to create work plans because the clients' demands are usually known more than one week in advance. Because three different objectives are considered, the MILP becomes the multi-objective MILP. Common techniques proposed to deal with the multi-objective MILP are the weighted sum, ϵ -constraint, and lexicographic methods. The weighted sum (Soland, 1979) is simple but quite efficient for a problem of a certain size, and are therefore commonly found in the literature. The ϵ -constraint method keeps only one of the objectives and restricts the others within user-specific values ϵ (Mavrotas, 2009). It therefore allows for non-extreme efficient solutions, which are not allowed for by the weighted-based methods. However, this method is not quite efficient for problems with more than two objectives, and choosing the range of the objective thresholds ϵ may require researchers with experience (Mavrotas, 2009). The lexicographic method is the simplest technique dealing with the multi-objective problem. A pre-defined order of objectives is established, and then a sequence of single-objective optimization problems is solved (Stanimirovic, 2012). The disadvantage of this method is that the decision-maker needs to determine the preferences for the objectives to establish the lexicographic order, which can be difficult (Stanimirovic, 2012). Moreover, a compromise between different objectives is not really obtained because they are completely hierarchized in order of importance. Given the advantages and disadvantages of these three techniques, the weighted sum is chosen for this study. A comparison between these techniques through numerical experiments will also be given in Section 4.2. Below is a presentation of the MILP model consisting of indices, parameters, variables, objectives, and constraints.

3.1. Indices

- Days of the planning horizon: $\{1, \dots, d, \dots, D\}$ ($D = 7$)
- Periods of a day: $\{1, \dots, t, \dots, T\}$ ($T = 6$)
- Agents: $\{1, \dots, i, \dots, N\}$
- Clients: $\{1, \dots, p, \dots, P\}$
- Tasks: $\{1, \dots, j, \dots, J\}$
- Skill types: $\{1, \dots, k, \dots, K\}$ ($K = 18$)
- Skill levels: $\{1, \dots, q, \dots, Q\}$, ($Q = 3$)

3.2. Parameters

- TCL_{jp} : Task j belongs to client p , =1 if yes, =0, otherwise, $\forall j = 1..J, \forall p = 1..P$
- TDA_j^d : Task j is required on day d , =1 if yes, =0, otherwise, $\forall j = 1..J, \forall p = 1..P$
- TD_j : Duration of task j , $\in \{1, 2, \dots, T\}$, $\forall j = 1..J$
- STW_j : Start time of task j , $\in \{1, 2, \dots, T\}$, $\forall j = 1..J$

- ETW_j : End time of task $j, \forall j \in \{1, 2, \dots, T\}, \forall j = 1..J, ETW_j - STW_j = TD_j$
- NBA_{jkq} : Number of agents having skill type k level q required by task $j, \in \{1, 2, \dots\}, \forall j = 1..J, \forall k = 1..K, \forall q = 1..Q$
- NB_j : Total number of agents required by task $j, NB_j = \sum_{k=1}^K \sum_{q=1}^Q NBA_{jkq}, \forall j = 1..J$
- SA_{ikq} : Agent i has skill type k level $q, =1$ if yes, $=0$ otherwise, $\forall i = 1..N, \forall k = 1..K, \forall q = 1..Q$
- CT_i : Contract type of agent i (see Table 2, column 1), $\in \{1, 2, \dots, 6\}, \forall i = 1..N$
- $MWTD_i$: Daily work time of agent i in case of being active on that day (in number of periods), $\in \{1, 2, \dots, T\}, \forall i = 1..N$. Agents' daily work time depends on their work contract: 3 consecutive periods for contract 12x36, between 1 and 3 periods for contract 4x20, and 2 consecutive periods for the other contracts.
- WWT_i : Weekly contract work time of agent i (see Table 2, column 6), $\forall i = 1..N$
- WTT_i : Weekly estimated travel time of agent i (see Table 2, column 7), $\forall i = 1..N$
- CTA_{ij} : Compatibility between the duration of task j and the contract type of agent $i, =1$ if compatible, $=0$ otherwise, $\forall i = 1..N, \forall j = 1..J$. Because agents are assumed to perform at most one task per day, they, therefore, cannot perform the task whose duration is shorter than their daily work time.
- IC_i : Initial modulation counter of agent i at the beginning of the planning horizon, $\forall i = 1..N$
- PR_i^t : Preference of agent i for period $t, = -1$: dislike, $=0$: neutral, $=1$: like, $\forall i = 1..N, \forall t = 1..T$
- TC_{ip} : Travel cost from agent site i to client site $p, \forall j = 1..J, \forall p = 1..P$
- TT_{ip} : Travel time from agent site i to client site $p, \forall j = 1..J, \forall p = 1..P$

3.3. Variables

- x_{ij}^t : $=1$ if agent i performs task j at period $t, =0$ otherwise, $\forall i = 1..N, \forall j = 1..J, \forall t = 1..T$. These variables are the main variables of the model that reflect the planning decisions. The other variables (see below) are complementary variables that help to build the model but can be derived from the main variables.
- y_{ij} : $=1$ if agent i performs task $j, =0$ otherwise, $\forall i = 1..N, \forall j = 1..J$
- z_i^{dt} : $=1$ if agent i works in period t of day $d, =0$ otherwise, $\forall i = 1..N, \forall d = 1..D, \forall t = 1..T$
- w_i^d : $=1$ if agent i works on day $d, =0$ otherwise, $\forall i = 1..N, \forall d = 1..D$
- u_i : $=1$ if agent i works during the planning horizon, $=0$, otherwise, $\forall i = 1..N$
- v_i : Real work time of agent i during the planning horizon including travel time, $\forall i = 1..N$
- mmc : Maximum absolute value of the modulation counters of all the agents
- b_i^{dt} : $=1$ if agent i has a type-1 work contract and works between periods t and $t+2$ of day $d, =0$ otherwise, $\forall i = 1..N, \forall d = 1..D, \forall t = 1..(T-2)$
- c_i^{dt} : $=1$ if agent i has a work contract type 2/4/5/6 and works between periods t and $t+1$ of day $d, =0$ otherwise, $\forall i = 1..N, \forall d = 1..D, \forall t = 1..(T-1)$

3.4. Objectives

In this model, three objectives are considered. The first objective is the minimization of

the total travel costs between agents' homes and their workplaces (Equ. 2). In the service-to-business domain, in some countries such as Brazil, it is common that the subcontracting company takes care of the travel costs of the agents. Reducing this type of costs can help reduce the service costs and thus increase the competitiveness of the company. The second objective is the maximization of the workload balance between agents by minimizing the maximum absolute value of their modulation counters (Equ. 3). The last objective is the maximization of the agents' preferences for assigned working periods (Equ. 4). These latter two objectives ensure the satisfaction of the agents that can help the company to ensure its employees do not leave to go to the competitors. These three objectives are aggregated in a weighted sum objective function (Equ. 1).

$$\text{Minimize: } \alpha\Pi_{TC} + \beta\Pi_{MC} - \gamma\Pi_{PR} \quad (1)$$

$$\bullet \Pi_{TC} = \sum_{i=1}^N \sum_{j=1}^J \sum_{p=1}^P (2 \times TC_{ip} \times TCL_{jp} \times y_{ij}) \quad (2)$$

$$\bullet \Pi_{MC} = mmc \quad (3)$$

$$\bullet \Pi_{PR} = \sum_{i=1}^N \sum_{d=1}^D \sum_{t=1}^T PR_i^t \times z_i^{dt} \quad (4)$$

3.5. Constraints

$$\bullet \sum_{i=1}^N SA_{ikq} \times x_{ij}^t \geq NBA_{jkq}, \forall j = 1..J, \forall k = 1..K, \forall q = 1..Q, \forall t = STW_j..ETW_j \quad (5)$$

$$\bullet \sum_{i=1}^N x_{ij}^t = NB_j, \forall j = 1..J, \forall t = STW_j..ETW_j \quad (6)$$

$$\bullet x_{ij}^t = 0, \forall i = 1..N, \forall j = 1..J, \forall t = 1..T/t < STW_j \text{ or } t > ETW_j \quad (7)$$

Constraints (5) and (6) ensure that for each skill type and skill level, the number of agents assigned to a task at each period within its time windows $[STW_j, ETW_j]$ has to equal the number of agents required. Constraints (5) use inequalities instead of equalities because some agents may have a skill level for some skill types that are not exploited by the task they are assigned (multi-skilled agents). These inequalities still allow the number of agents of each skill type and skill level assigned to a task to be greater than the number of agents it actually requires. Constraints (6) are added to ensure that these numbers are equal globally. Constraints (7) make sure that no agent is assigned to a task at any period outside of its time windows.

$$\bullet y_{ij} \leq CTA_{ij}, \forall i = 1..N, \forall j = 1..J \quad (8)$$

$$\bullet \sum_{j=1}^J TDA_j^d \times y_{ij} = w_i^d, \forall i = 1..N, \forall d = 1..D \quad (9)$$

Constraints (8) ensure the compatibility between a task duration and an agent contract type. Agents can only be assigned to a task whose duration is greater than or equal to their daily work capacity. Constraints (9) ensure that each agent is assigned to at most one task per day.

$$\bullet \sum_{t=1}^T x_{ij}^t = MWTD_i \times y_{ij}, \forall i = 1..N/CT_i \in \{1,2,4,5,6\}, \forall j = 1..J \quad (10)$$

$$\bullet y_{ij} \leq \sum_{t=1}^T x_{ij}^t \leq 3 \times y_{ij}, \forall i = 1..N/CT_i = 3, \forall j = 1..J \quad (11)$$

- $\sum_{j=1}^J TDA_j^d \times x_{ij}^t = z_i^{dt}, \forall i = 1..N, \forall d = 1..D, \forall t = 1..T$ (12)

- $\sum_{t=1}^T z_i^{dt} = MWTD_i \times w_i^d, \forall i = 1..N/CT_i \in \{1,2,4,5,6\}, \forall d = 1..D$ (13)

- $w_i^d \leq \sum_{t=1}^T z_i^{dt} \leq 3 \times w_i^d, \forall i = 1..N/CT_i = 3, \forall d = 1..D$ (14)

- $u_i \leq \sum_{d=1}^D w_i^d \leq D \times u_i, \forall i = 1..N$ (15)

Constraints (10)-(15) show the relations between the problem variables. Because agents (with a contract type different from 4x20) are assumed to perform a maximum of one task per day, constraints (10) are used to ensure that if they perform a task, they have to work with their daily capacity $MWTD_i$. Constraints (11) consider the specific case of agents of contract 4x20 and imply that they can perform a task with at most their maximum daily capacity of 3 periods (12h). However, they can perform a task whose size is bigger than 12 hours by working together with another agent. Constraints (12) ensure that agents work in a particular period of a day if they perform a task in that period of that day. Constraints (13) imply that if agents (with a contract type different from 4x20) work on a day, they have to work at their daily capacity $MWTD_i$. Constraints (14) ensure that agents with contract 4x20 cannot exceed their maximum daily capacity of 3 periods (12h). Constraints (15) make sure that agents work during the planning horizon if they work on at least one of its days.

- $\sum_{t=1}^{T-2} b_i^{dt} \leq 1, \forall i/CT_i = 1, \forall d = 1..D$ (16)

- $\left\{ \begin{array}{l} z_i^{dt} = b_i^{d(t-2)} + b_i^{d(t-1)} + b_i^{dt}, \forall t = 3..4 \\ z_i^{d5} = b_i^{d3} + b_i^{d4} \\ z_i^{d6} = b_i^{d4} \\ z_i^{d2} = b_i^{d1} + b_i^{d2} \\ z_i^{d1} = b_i^{d1} \end{array} \right., \forall i/CT_i = 1, \forall d = 1..D$ (17)

- $\sum_{t=1}^{T-1} c_i^{dt} \leq 1, \forall i/CT_i \in \{2,4,5,6\}, \forall d = 1..D$ (18)

- $\left\{ \begin{array}{l} z_i^{dt} = c_i^{d(t-1)} + c_i^{dt}, \forall t = 2..5 \\ z_i^{d1} = c_i^{d1} \\ z_i^{d6} = c_i^{d5} \end{array} \right., \forall i/CT_i \in \{2,4,5,6\}, \forall d = 1..D$ (19)

- $\left\{ \begin{array}{l} z_i^{d1} + z_i^{dt} \leq u_i, \forall t = 4..6 \\ z_i^{d2} + z_i^{dt} \leq u_i, \forall t = 5..6, \forall i/CT_i = 3, \forall d = 1..D \\ z_i^{d3} + z_i^{d6} \leq u_i \end{array} \right.$ (20)

- $z_i^{dt} + z_i^{d(t+2)} - z_i^{d(t+1)} \leq u_i, \forall t = 1..4, \forall i/CT_i = 3, \forall d = 1..D$ (21)

Constraints (16) and (17) ensure the continuity of the working periods of agents of shift contract 12x36. An agent of this contract type can perform tasks only between three consecutive periods. Similarly, constraints (18) and (19) ensure the continuity of the working periods of agents of shift contract 8x24 and non-shift contracts; these agents can perform tasks only between two consecutive periods. Constraints (20) and (21) ensure the

continuity of the working periods of agents of shift contract 4x20; if an agent of this contract works 2 or 3 periods on a day, these periods have to be consecutive.

$$\bullet \begin{cases} z_i^{dt} - z_i^{d_1t} \leq 2 - (w_i^d + w_i^{d_1}) \\ z_i^{dt} - z_i^{d_1t} \geq w_i^d + w_i^{d_1} - 2 \end{cases}, \forall d = 1..D, \forall d_1 = (d+1)..D, \forall i/CT_i \in \{4,5,6\} \quad (22)$$

Constraints (22) ensure that if non-shift agents (contract types 4, 5 or 6) work in a period of a day, they have to work in the same period on the other days of the week (except for their days off).

$$\bullet v_i = 4 \times \sum_{d=1}^D \sum_{t=1}^T z_i^{dt} + 2 \times \sum_{j=1}^J \sum_{p=1}^P TT_{ip} \times TCL_{jp} \times y_{ij}, \forall i = 1..N \quad (23)$$

$$\bullet mmc \geq v_i - (WWT_i + WTT_i) \times u_i + IC_i, \forall i = 1..N \quad (24a)$$

$$\bullet mmc \geq -[v_i - (WWT_i + WTT_i) \times u_i + IC_i], \forall i = 1..N \quad (24b)$$

Constraints (23) refer to agents' total real work time during the planning horizon, including their travel time. Constraints (24a) and (24b) define the maximum absolute value of the modulation counters of all the agents.

Contract type 1 (12x36)

$$\bullet z_i^{dt} = z_i^{(d+2)t}, \forall i = 1..N/CT_i = 1, \forall d = 1..(D-2), \forall t = 1..T \quad (25A)$$

$$\bullet \sum_{d_1=d}^{d+1} \sum_{t=1}^T z_i^{d_1t} = 3 \times u_i, \forall i = 1..N/CT_i = 1, \forall d = 1..(D-1) \quad (26A)$$

Contract type 2 (8x24)

$$\bullet z_i^{dt} = z_i^{(d+1)(t+2)}, \forall i = 1..N/CT_i = 2, \forall d = 1..(D-1), \forall t = 1..(T-2) \quad (27A)$$

$$\bullet z_i^{dt} = z_i^{(d+2)(t-T+2)}, \forall i = 1..N/CT_i = 2, \forall d = 1..(D-2), \forall t = (T-1)..T \quad (28A)$$

$$\bullet \sum_{d_1=d}^{d+3} \sum_{t=1}^T z_i^{d_1t} = 6 \times u_i, \forall i = 1..N/CT_i = 2, \forall d = 1..(D-3) \quad (29A)$$

Constraints (25A) and (26A) are applied to agents of contract type 1. Constraints (25A) imply that if agents work in period t on day d , they also have to work in the same period 2 days later. Constraints (26A) ensure that if agents of this contract type are used, they have to work exactly 3 periods of 4 hours for any two consecutive days. Similarly, constraints (27A), (28A) and (29A) are applied to agents of contract type 2. Constraints (27A) imply that if agents work in period t ($t \leq T-2$) on day d , they also have to work in period $t+2$, one day later. Constraints (28A) ensure that if agents work in periods $T-1$ or T , on day d , they also have to work in period 1 or 2, two days later. Constraints (29A) ensure that if agents of this contract type are used, they have to work 6 periods of 4 hours for any four consecutive days.

Contract type 3 (4x20)

- $6 \times u_i \leq \sum_{d=1}^D \sum_{t=1}^T z_i^{dt} \leq 8 \times u_i, \forall i = 1..N/CT_i = 3$ (30A)

- $\sum_{t_1=t}^T z_i^{dt_1} + \sum_{t_2=1}^{t-T+3} z_i^{(d+1)t_2} \leq 1, \forall i = 1..N/CT_i = 3, \forall d = 1..(D-1), \forall t = (T-2)..T$ (31A)

Constraints (30A) and (31A) are applied to agents of contract type 3. Constraints (30A) imply that each agent of contract 4x20 has to work between 6 and 8 periods of 4 hours per week. Constraints (31A) ensure the minimum time lag between two consecutive working periods (no more than one working period for any duration of 16 hours).

Contract type 4 (5x2)

- $$\begin{cases} w_i^2 + w_i^7 = u_i \\ w_i^1 + w_i^6 = u_i \\ w_i^1 + w_i^7 \leq u_i \\ w_i^3 = w_i^4 = w_i^5 = u_i \end{cases}, \forall i = 1..N/CT_i = 4$$
 (32A)

Contract type 5 (6x1)

- $$\begin{cases} w_i^1 + w_i^7 = u_i \\ w_i^2 = w_i^3 = w_i^4 = w_i^5 = w_i^6 = u_i \end{cases}, \forall i = 1..N/CT_i = 5$$
 (33A)

Contract type 6 (5x1)

- $$\begin{cases} w_i^1 + w_i^6 = u_i \\ w_i^1 = w_i^7 \\ w_i^2 = w_i^3 = w_i^4 = w_i^5 = u_i \end{cases}, \forall i = 1..N/CT_i = 6$$
 (34A)

Agents of contract type 4 have to work five consecutive days during the week that can be from day 1 to day 5, day 2 to day 6, or day 3 to day 7. In any of these three cases, these agents have to work on days 3, 4 and 5 (the last equations of constraints (32A)). The other two days can be chosen between days 1 and 2, days 2 and 6, or days 6 and 7 (the first three equations of constraints (32A)). Agents of contract type 5 have to work six consecutive days during the week that can be from day 1 to day 6, or day 2 to day 7. In any of these two cases, these agents have to work from day 2 to day 6. The other day can be chosen between day 1 and day 7 (33A). Agents of contract type 6 have to work five consecutive days and have a break of 1 day for any duration of 6 days. These consecutive days can be from day 1 to day 5, or day 2 to day 6. Therefore, they can work 6 days within the week, taking day 6 off, or 5 days from day 2 to day 6, taking both days 1 and 7 off. In any of these two cases, these agents have to work on days 2, 3, 4 and 5 (the last equations of constraints (34A)). The other workdays can be day 6 or days 1 and 7 (the first two equations of constraints (34A)).

4. Experiments

4.1. Data

The benchmark, which is used to generate instances for experiments, is built on the database provided by the Brazilian company. It has 672 agents and 1,343 tasks belonging to 66 clients. Because the objective is to focus on the investigation of the problem characteristics, the territorial decomposition technique, which is currently considered by the company, is used to reduce the problem size. Preliminary experiments to evaluate the impact of the instance sizes on the feasibility and optimality of the problem solving have already been performed (Doan et al. 2019). The results show that the method is interesting for a problem of a certain size (at least 15 agents and 50 tasks). In this paper, the numbers of agents and tasks are considered between 30 and 60, and 60 and 100 respectively, which are typical numbers of a district in the benchmark.

Four different scenarios are considered in these experiments. The original scenario (scenario 0) corresponds to the current situation of the company where the agents are mono-skilled and only four work contracts are used. The instances of the other three scenarios are not completely different from the original instances used for scenario 0; depending on each specific scenario, only some characteristics are modified. Scenario 1 also considers only four work contracts but agents are multi-skilled. Scenario 2 considers only mono-skilled agents but two new work contracts (8x24 and 4x20) are added. Scenario 3 considers both multi-skilled agents and two new work contracts.

Table 4. Characteristics of the 30 instances used for the experiments (scenario 3)

Indicator / Characteristic	Average	Min	Max
Number of clients	4.5	3	6
Number of tasks	84.2	71	95
Number of agents	47.2	37	60
Number of agents 12x36	7.6	4	12
Number of agents 8x24	7.3	4	12
Number of agents 4x20	11.3	5	19
Number of agents 5x2	6.6	0	14
Number of agents 6x1	12.5	7	19
Number of agents 5x1	1.9	0	6
Shift / non-shift rate	57%:43%	33%:67%	73%:27%

Table 4 shows the characteristics of the 30 final instances used for the experiments. Among the four scenarios considered, the characteristics of the 30 final instances of scenario 3, which corresponds to the consideration of the six work contracts, are presented here.

4.2. Methodology

The CPLEX software, installed on a powerful computer (Intel Xeon CPU E5-1620 V3, 2x3.5 GHz, 64G of RAM), is used to solve the problems. The maximum calculation time allowed for each experiment is 10 hours and the relative MIP gap tolerance (the gap between the best integer objective and the objective of the best node remaining) is 1%.

First, an analysis on common multi-criteria optimisation techniques (introduced in Section 3) is performed for the original problem. These techniques, especially the weighted sum and the ϵ -constraint, were tested with carefully chosen parameters. The results (Table 5) show that among the four techniques considered, the weighted sum method gives the shortest calculation time and a very good compromise between the three criteria (TC, MC, and PR). Therefore, it is interesting to use this multi-criteria optimisation technique to solve the problem.

Table 5. Comparison between common multi-criteria optimisation techniques

Optimisation technique		Lexicographic 1	Lexicographic 2	ϵ -constraint	Weighted sum
Run-time (s)	Average	2,197	788	312	220
	Max	37,366	5,931	2,545	775
Criteria	TC	2,141.6	2,141.9	2,192.2	2,198.1
	MC	18.2	19.8	17.2	17.0
	PR	60.2	76.0	85.4	90.0

Lexicographic 1: TC>MC>PR, Lexicographic 2: TC>PR>MC

With this weighted sum technique, the experiments are performed for four scenarios that correspond to consideration of no lever, of each of the two levers separately, and of both of them respectively (Figure 3).

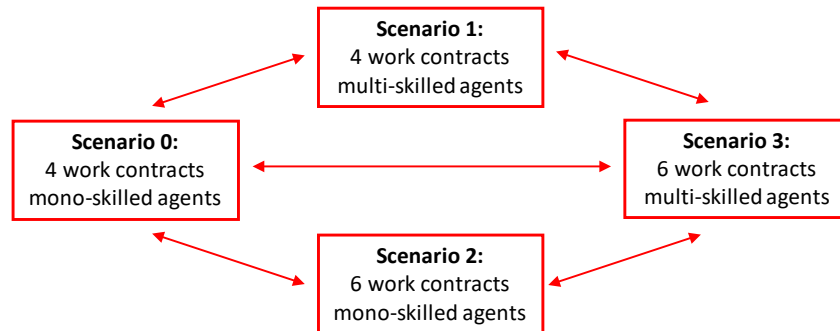


Figure 3. Combinations of the two levers proposed in the four scenarios of experiments

For each scenario and each of the 30 instances considered, four different problems are solved. The first three are mono-objective problems that are associated with TC (total agent travel costs), MC (maximum absolute value of agents' modulation counters), and PR (total agent preferences for working periods), respectively. The fourth problem uses a weighted sum of TC, MC, and PR as the objective formulation. The associated coefficients α (of TC), β (of MC), and γ (of PR) are chosen to be the inverses of the three optimal objective values TC^* , MC^* and PR^* obtained previously. This multi-objective formulation gives an equal contribution to the global objective for each criterion. To confirm this choice, a sensitivity analysis is performed to see whether, when the coefficients (α , β , γ) are varied around the chosen set (α_0 , β_0 , γ_0), the values of the three criteria obtained with new sets of coefficients are quite different from those obtained with the former chosen set. Ten sets of coefficients that vary within 5% of the chosen set are generated. The results (Table 6) show that the three criteria (TC, MC, and PR) obtained with new sets of coefficients vary very little around those obtained with the former chosen set. On average, they vary less than 0.1% for all the instances and experiments. The largest

variations for TC and MC is 1.8%, while it is nearly zero for PR. These results mean that the performance of the solutions obtained is generally stable with the coefficients (α , β , γ) chosen, which is interesting in practice.

Table 6. Sensitivity analysis for the original problem

Exp.	α	β	γ	ΔTC_{\min}	ΔTC_{\max}	ΔMC_{\min}	ΔMC_{\max}	ΔPR_{\min}	ΔPR_{\max}
1	$0.95\alpha_0$	$0.95\beta_0$	$0.95\gamma_0$	~ 0	~ 0	~ 0	~ 0	~ 0	~ 0
2	$0.95\alpha_0$	$0.95\beta_0$	$1.05\gamma_0$	~ 0	~ 0	~ 0	~ 0	~ 0	~ 0
3	$0.95\alpha_0$	$1.05\beta_0$	$1.05\gamma_0$	~ 0	1.8%	-1.8%	~ 0	~ 0	~ 0
4	α_0	β_0	$0.95\gamma_0$	~ 0	~ 0	~ 0	~ 0	~ 0	~ 0
5	α_0	$1.05\beta_0$	$0.95\gamma_0$	~ 0	1.8%	-1.8%	~ 0	~ 0	~ 0
6	α_0	$1.05\beta_0$	$1.05\gamma_0$	~ 0	1.8%	-1.8%	~ 0	~ 0	~ 0
7	$1.05\alpha_0$	$0.95\beta_0$	$1.05\gamma_0$	-1.7%	~ 0	~ 0	1.8%	~ 0	~ 0
8	$1.05\alpha_0$	β_0	$0.95\gamma_0$	~ 0	0.1%	~ 0	~ 0	~ 0	~ 0
9	$1.05\alpha_0$	$1.05\beta_0$	γ_0	~ 0	1.8%	-1.8%	~ 0	~ 0	~ 0
10	$1.05\alpha_0$	$1.05\beta_0$	$1.05\gamma_0$	~ 0	~ 0	~ 0	~ 0	~ 0	~ 0

~ 0 : $<0.05\%$

Three indicators are used for the evaluation, which include the calculation time (if the problem is solved optimally), the GAP value (if the problem is not solved optimally but a solution is obtained), and the values of the three criteria obtained at the cut-off time. The calculation times and the GAP values are used to evaluate the complexity of problem solving while the values of the three criteria allow comparing the quality of the solutions obtained between scenarios.

4.3. Experiment results

4.3.1. Problem's complexity

The problem's complexity is considered through the problem size (Table 7), the GAP values of the solutions obtained (Table 8) and the calculation time needed to solve the problem using the CPLEX software (Table 9).

The problem size is related to the numbers of clients (P), tasks (J), agents (N), and the number of variables and constraints of the MILP model. Because the average numbers of clients and tasks are considered the same for all problems and scenarios ($\bar{P} = 4.5$, $\bar{J} = 84.2$), the investigation of the problem size focuses on the numbers of agents, variables, and constraints.

Table 7. Four scenarios' problem size

Scenario	0	1	2	3
Average number of				
Agents (N)	42.9	42.9	47.2	47.2
Variables	11402.8	11568.7	14951.4	15384.8
Constraints	6536.2	6575.3	9684.7	9988.0

Table 7 shows that off the four scenarios considered, the problem size is not quite different between scenario 0 and scenario 1, or between scenario 2 and scenario 3. This means that using mono-skilled or multi-skilled agents does not change the problem size.

Without surprise, the difference is significant between the scenarios with six contracts (scenarios 2 and 3) and those with four contracts (scenarios 0 and 1). The orders of magnitude of the difference are 10%, 30%, and 50% for the numbers of agents, variables, and constraints respectively.

Table 8. Number of instances in which the GAP value of the solution obtained is less than 1%, between 1% and 5%, and greater than 5%

Scenario	0			1			2			3		
	<1%	1-5%	>5%	<1%	1-5%	>5%	<1%	1-5%	>5%	<1%	1-5%	>5%
Mono TC	30	0	0	30	0	0	0	25	5	0	28	2
Mono MC	30	0	0	30	0	0	30	0	0	30	0	0
Mono PR	30	0	0	30	0	0	30	0	0	30	0	0
Multi	30	0	0	30	0	0	3	19	8	3	20	7

GAP value: the relative gap between the best bound (objective of the best node remaining) and the best integer objective obtained

Table 8 shows that the resolution method proposed is very efficient for the first two scenarios, which consider only four work contracts, where the four problems are solved optimally for all the 30 instances. For the last two scenarios, which consider six work contracts, the resolution method is very efficient for the two mono-objective problems with MC or PR when they are solved optimally for all 30 instances. Moreover, the resolution method is also quite efficient for the mono-objective problem with TC and the multi-objective problem, where most of the solutions obtained within 10 hours are near-optimal (GAP value is between 1% and 5%).

Table 9 again confirms the efficiency of the resolution method on the four problems in the first two scenarios and the two mono-objective problems with MC and PR in the last two scenarios. The calculation times are quite small (less than 30 minutes) for these problems in these scenarios. These results also show that the mono-objective problem with TC and the multi-objective problem in the last two scenarios, which consider six work contracts, are the most complex among the four problems studied, which need almost the maximum calculation time of 10 hours.

Table 9. Average calculation time for the four problems in different scenarios (minutes)

Scenario /Problem	0	1	2	3
Mono TC	1.1	0.9	600.0	597.4
Mono MC	1.2	1.9	6.8	4.7
Mono PR	0.6	0.9	21.2	15.2
Multi	1.0	1.3	506.6	487.1

These results above are not surprising. The use of six contracts, especially the 4x20 contract, significantly increases the number of possible combinations between contracts to fulfil a task, and therefore increases the solution space and the complexity of the problem solving. For the last two scenarios, the level of complexity in terms of optimization of the mono-objective problems with MC and PR is lower than that of the mono-objective problem with TC and the multi-objective problem. This is because in order to optimize the total transport costs (TC), the CPLEX software's algorithm (branch and bound), which is used to solve the MILP model, has to search for an optimal solution

between a huge number of feasible solutions whose objective values (TC) are very close. This increases the calculation time for the algorithm to cut a ‘bad’ branch and jump into a new branch with a better objective value. By contrast, for the mono-objective problems with MC and PR, it is much easier for the algorithm to cut a ‘bad’ branch when the objective values of feasible solutions are not quite close.

Section 4.3.2 compares the scenarios with and without the multi-skilled agents. Section 4.3.3 considers the scenarios with and without the two new flexible contracts. Finally, section 4.3.4 compares the scenarios with both multi-skilled agents and two new flexible contracts, and those without the consideration of these two.

4.3.2. Multi-skilled agents vs mono-skilled agents

These experiments aim at comparing the quality of the solutions of the four problems obtained in the scenarios with and without the first lever, the use of multi-skilled agents. This comparison is performed in two different contexts, with and without the second lever, the use of two new work contracts. In each context, the four problems are solved for the 30 instances in the two corresponding scenarios to obtain the values of the three criteria considered. Then, for each instance, the percentages of improvement of these criteria in the case considering multi-skilled agents, in comparison to the case with mono-skilled agents are calculated. The average percentage of improvement of the 30 instances is used to evaluate the quality of the solutions of the four problems.

The results (Table 10) show that in comparison to the scenarios considering only mono-skilled agents, those considering multi-skilled agents (4 or 6 contracts) always give solutions with slightly better TC, MC, and PR for all three mono-objective problems (between 1.9% and 5.4%). Moreover, the solutions obtained when considering multi-skilled agents also have a better compromise between the three criteria for the multi-objective problems than when considering only mono-skilled agents, with percentages of improvement between 1.4% and 3.9% for all the criteria. This is reasonable because using multi-skilled agents increases the number of alternatives for each solution. If a set of values of variables is a solution in the case of mono-skilled agents, it is also a solution in the case of multi-skilled agents. Therefore, the solution space in the case of multi-skilled agents is bigger than and includes that in the case of mono-skilled agents. Extending the solution space obviously increases the chance to find a better solution for the problem.

Table 10. Average percentages of improvement of TC, MC, and PR of the four problems when considering multi-skilled agents in comparison to mono-skilled agents

Context		4 work contracts	6 work contracts
Scenarios considered		1 vs 0	3 vs 2
Objective formulation	Criterion		
Mono TC	TC	+1.9%	+2.3%
Mono MC	MC	+5.4%	+2.0%
Mono PR	PR	+3.5%	+3.3%
Multi	TC	+1.5%	+1.7%
	MC	+3.2%	+1.4%
	PR	+3.9%	+2.2%

In conclusion, the solutions obtained in the scenarios with multi-skilled agents dominate those in the case of mono-skilled agents. Therefore, agents with multiple skills

should be prioritized during recruitment in comparison to mono-skilled agents. Moreover, the training should not only consolidate agents' main skill but also develop their secondary skills. However, further analysis should be performed to determine a good proportion between multi-skilled and mono-skilled agents to make use of the multiple skills of agents to limit travel costs and improve agent satisfaction, and to avoid a steep increase of workforce costs if agents' salary depends on their skills (Stolletz and Zamorano 2014).

4.3.3. Six work contracts vs four work contracts

These experiments investigate the second lever, the introduction of two new work contracts, in the two contexts, with and without the consideration of the multi-skilled agents (columns 3 and 4, Table 11 respectively). In a similar way to the first experiments, the average percentages of deviation of the 30 instances between the two scenarios in each context are used to evaluate the quality of the solutions of the four problems (Table 11).

Table 11. Average percentages of deviation of TC, MC, and PR of the four problems when considering six work contracts in comparison to four work contracts

Context		Mono-skilled agents	Multi-skilled agents
Scenarios considered		2 vs 0	3 vs 1
Objective formulation	Criterion		
Mono TC	TC	-3.4%	-2.9%
Mono MC	MC	+3.2%	+0.6%
Mono PR	PR	+46.4%	+46.6%
Multi	TC	-11.7%	-11.6%
	MC	+3.0%	+1.9%
	PR	+41.9%	+41.3%

The experiment results (Table 11) show that in comparison to the two scenarios using 4 work contracts, those using 6 work contracts give the solutions with slightly better MC values for the mono-objective problem with MC and the multi-objective problem (about 3% in the context of mono-skilled agents and 1% in the context of multi-skilled agents). Moreover, the solutions obtained have significantly better PR values for the mono-objective problem with PR and the multi-objective problem (between 41-46% for both the contexts associated with mono-skilled and multi-skilled agents). However, the TC values obtained when using six contracts (mono-skilled or multi-skilled agents) are slightly worse for the mono-objective problem with TC and considerably worse for the multi-objective problem (about 3% and 11% respectively). These results are quite interesting for the company when a limited loss of the company costs can significantly increase the agent satisfaction associated with the workload balance and the agent preferences for working periods. The conclusions above are explicable because, in order to perform the same task, more 4x20 and 8x24 agents have to be used than when 12x36 agents are considered. The total number of agents (also the total number of work trips) in the scenarios using six work contracts is, therefore, bigger than that in the case of using only four work contracts. It is obvious that the total travel costs (TC) of a bigger number of work trips are bigger. Moreover, having a very flexible start and end times per day and a flexible number of workdays per week increases agents' ability to combine with other

contracts. These types of flexibility make it possible to find an assignment that can increase the total preferences for all the company agents. They also allow the agents to fulfil their required workload easily, so that they can reduce their modulation counters.

4.3.4. Multi-skilled agents and six work contracts vs mono-skilled agents and four work contracts

The average percentages of deviation of all three criteria of the four problems in the case using both the levers are better than when using only the second lever: two new work contracts (Table 12). For the three mono-objective problems, the objective criteria TC, MC, and PR are, on average, improved 2.2%, 2.2% and 1.5% more than when considering only the second lever. In comparison to the consideration of the first lever only, that is, multi-skilled agents, the percentages of deviation of TC when considering the two levers simultaneously are worse for both the mono-objective problem with TC and the multi-objective problem. However, the percentages of deviation of MC and PR are slightly and distinctly better for both the mono-objective problems with MC and PR and the multi-objective problem. This result means that a better compromise between the criteria is obtained when considering both levers.

Table 12. Average percentages of deviation of TC, MC, and PR of the four problems when considering only the first lever, only the second lever, and the two levers simultaneously

Scenarios considered		1 vs 0	2 vs 0	3 vs 0
Objective formulation	Criterion	Multi-skilled agents only	Two new work contracts only	Both multi-skilled agents and two new work contracts
Mono TC	TC	+1.9%	-3.4%	-1.20%
Mono MC	MC	+5.4%	+3.2%	+5.40%
Mono PR	PR	+3.5%	+46.4%	+47.90%
Multi	TC	+1.5%	-11.7%	-10.30%
	MC	+3.2%	+3.0%	+4.70%
	PR	+3.9%	+41.9%	+42.90%

Briefly, the solutions obtained when considering both levers (multi-skilled agents and using two new work contracts) dominate those obtained when considering only two new work contracts. Moreover, these considerations give the solutions with a better compromise between the three criteria than in the case that only multi-skilled agents are considered; a limited degradation of the company's costs can allow a slight increase in the workload balance between agents and a significant increase in their preference satisfaction. The company can, therefore, implement these two levers at the same time without worrying that one limits the impact of the other. However, further analysis should be performed to evaluate the interaction of these two levers.

5. Conclusions and perspectives

This article studies the impact of flexible work contracts and multi-skilled agents on a multi-objective workforce planning problem. In order to cope with increasing numbers

of new variable demands by clients, the company considers these two levers to increase the level of workforce flexibility. Furthermore, the company wants to minimize its agents' travel costs (TC) and to maximize agent satisfaction by maximizing the workload balance between agents (MC), and their preferences for working periods (PR). The mixed-integer linear programming method was used to model and solve four different problems including three mono-objective problems with TC, MC, and PR and one multi-objective problem. Thirty realistic instances, built on a real database provided by a Brazilian company, were used to perform numerical experiments. The results show that the resolution approach is capable of giving optimal or near-optimal solutions in more than 70% of the problems considered, including multi-objective problems. In terms of solution quality, considering multi-skilled agents slightly improves all three criteria considered for both the mono-objective and multi-objective problems. Introducing two new work contracts gives a better compromise between these three criteria; a reasonable increase of the company costs can slightly improve the workload balance between agents and significantly improve the agent preference satisfaction for working periods for both the mono-objective and multi-objective problems.

These results give the company managers the decision-making support to improve their strategy for workforce development. All the recruitment, training, and assignment should be considered. First, a good set of the workforce should have a diversity of contract types, especially flexible contracts. Then, agents with multiple skills should be prioritized for recruitment, rather than mono-skilled agents. Finally, the training should not only consolidate agents' main skill but also develop their secondary skills.

The company should however also take into account some hidden economic and social impacts when considering these levers. Using multi-skilled agents may be more costly than mono-skilled agents. Training an agent in different skills also increases the training costs. A reasonable proportion between multi-skilled and mono-skilled agents should, therefore, be considered (Stolletz and Zamorano 2014). The introduction of multi-skilled agents not only improves the travel costs and agent satisfaction but also reduces the workforce's lassitude when a multi-skilled agent can work for different workplaces at different times. Flexible contracts can increase workforce flexibility but they also affect workforce stability because these agents are usually less loyal to the company than those with more stable contracts. A reasonable proportion of agents with flexible and with stable contracts should, therefore, be obtained.

As follow-up, an approximation solution method, which provides solutions of good quality in reasonable calculation time, could be developed to solve the multi-objective on larger problems. The Pareto frontiers could then be implemented to obtain solutions with different levels of compromise between the three criteria of the multi-objective problem. Finally, further refinements could be tested about travel times. They can be assumed to vary at different periods of a day, and the travel times from home to work and from work back home might also be different. Using company buses to transport agents to their workplaces instead of public transport or private means can reduce the total travel costs. However, the vehicle routing problem has also to be considered when buses are used.

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