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An optimization-based framework for personal scheduling during pandemic events

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Abstract In recent years, companies have faced the challenge of adapting to new guidelines and strategies aimed at preventing and reducing the transmission of COVID-19 within the workplace. An essential aspect of this adaptation is effectively managing the workday schedule to minimize social contact. This paper introduces a comprehensive optimization framework designed to automate the planning of employee schedules during pandemic events. Our framework utilizes integer linear programming to establish a set of general constraints that can accommodate various types of distancing restrictions and cater to different objective functions. To employ the framework, a company simply needs to instantiate a subset of these constraints along with an objective function based on its specific priorities. We conducted tests on our scheduling framework within three distinct real-life companies, yielding promising results. Our approach successfully increased the number of in-person workers by 15%, all while adhering to the social distancing restrictions mandated by these companies. Furthermore, the solutions generated by our method were implemented and validated within these organizations.

Keywords: Pandemic, Integer programming, COVID-19, personal scheduling

1 Introduction

The disease known as COVID-19, caused by the SARS-CoV-2 coronavirus, first emerged in the city of Wuhan, China, in late 2019 and rapidly spread worldwide in early 2020. After being classified as a pandemic by the World Health Organization (WHO) [Jebril, 2020], countries implemented border closures in an attempt to control the transmission of the virus. Although some individuals experience only mild symptoms and are minimally affected by the virus, many others experience severe conditions that require ventilators or intensive care unit (ICU) treatment.

In this scenario, both public and private organizations worldwide are compelled to adapt to government decrees and guidelines, encompassing hygiene protocols, social distancing measures, and safety protocols. Extensive social distancing measures, as highlighted by Coroiu *et al*. [2020], have demonstrated the potential to significantly reduce disease transmission, particularly when social contacts are reduced by at least 60%. Consequently, organizations must effectively manage their workday schedules to mitigate the virus's spread and safeguard the well-being of their employees. To achieve this objective, organizations have implemented various approaches, including the reduction of working hours, temporary work contract suspensions, the implementation of diversified working shifts, and the adoption of alternative work arrangements such as remote work and telecommuting. These measures aim to adapt the traditional working environment and facilitate social distancing while maintaining productivity and ensuring the safety of the workforce.

In a pandemic scenario, companies face the daunting challenge of optimizing employee shifts and working schedules to ensure business continuity while adhering to government guidelines. This complex task involves balancing multiple objectives, including minimizing social contact, reducing the number of employees present, controlling service costs, and accommodating home office hours. As the number of workers increases, the complexity of this problem grows exponentially, necessitating the development of an automated mechanism to relieve companies from the burden of manually creating these schedules.

This study introduces a novel framework based on Mixed Integer Linear Programming (MILP) for efficiently scheduling work hours during pandemic events. Our framework incorporates a comprehensive set of general parameters and constraints that can be customized to align with various government decrees and guidelines aimed at mitigating the spread of the virus. To validate the effectiveness of our approach, we applied it to three real-life Brazilian companies, showcasing its adaptability to different organizational requirements and objectives. Comparisons were made between the schedules generated by our framework and the existing manual schedules currently in use by these companies.

Experimental results demonstrate that our approach, with minimal computational effort, consistently produces work hour schedules that surpass the manually crafted ones. Moreover, the solutions generated by our method were successfully implemented and validated within these organizations, further validating the practicality and efficacy of our approach. It is important to highlight that although our method has been considered in a pandemic context, as the results show, it can be easily adapted to any context in which workers need to adapt to non-conventional work scenarios, such as remote work. The remainder of the paper is organized as follows. Section 2 presents the related work on the problem. In Section 3, we describe the proposed MILP framework. Section 4 shows the experimental results, in which we evaluate the proposed framework in three brazilian companies. Finally, Section 5 contains our concluding remarks.

2 Related work

The COVID-19 pandemic has introduced many new optimization problems that possess unique characteristics, distinguishing them from conventional models. Notably, in the field of vehicle routing problems (VRPs), Tordecilla *et al.* [2021] devised daily routing plans to maximize item pickups within limited time frames, thereby minimizing drivers' exposure to the virus. Chen *et al.* [2020] proposed a multi-vehicle multi-trip VRP for contactless joint distribution services. Pacheco and Laguna [2020] addressed a VRP focused on urgent face shield deliveries during the pandemic. In the domain of supply chain distribution, Perdana *et al.* [2020] discussed an optimization model to manage the impact of COVID-19 on the food supply network, particularly through regional food hubs, while accounting for uncertainties. Moosavi and Hosseini [2021] conducted an investigation into real case studies concerning supply chain disruptions in the aftermath of the COVID-19 outbreak. Ambrogio *et al.* [2022] holistically analyzed the impacts of COVID-19 on workforce dynamics and supply resilience. In healthcare systems, Geibinger *et al.* [2021] presented a constraint programming model that incorporates various requirements essential for day-to-day hospital operations, alongside additional constraints imposed by the pandemic situation. Lastly, certain works have addressed social distancing considerations. For instance, Contardo and Costa [2022] tackled the problem of maximizing the seating capacity of a dining room while maintaining appropriate social distancing between chairs at different tables.

Personal scheduling has been a topic extensively explored in the literature over several decades. For a comprehensive understanding, we recommend referring to the detailed search conducted by Ernst *et al.* [2004a,b], the complex models and results presented by Brucker *et al.* [2011], and the classification based on demands and shifts proposed by Ernst *et al.* [2004a]. However, the outbreak of the COVID-19 pandemic caused by the SARS-CoV-2 virus has brought about significant changes in workforce management practices. This has resulted in a greater need for flexibility, such as the adoption of remote work and modifications to work shifts. As far as we know, there are only three authors who have specifically addressed the challenges of personal scheduling in the COVID-19 era: Zucchi *et al.* [2021], Guerriero and Guido [2021], and Mehrizi *et al.* [2022].

The approach proposed by Zucchi *et al.* [2021] offers a novel MILP formulation to effectively generate personal schedules for employees during the COVID pandemic in a large drug distributor warehouse in Italy. The main objective is to prevent virus transmission by dividing employees into distinct, non-overlapping groups and assigning them to different shifts. The generated schedule must adhere to the contractual working hours of each employee while aiming to minimize the overall deviation between the contracted and actual working hours. Notably, the study demonstrates that the solution derived from this formulation surpasses the schedule produced by the company itself.

Another work, presented by Guerriero and Guido [2021], proposes an optimization model to address flexible team scheduling problems, taking into account demand requirements, personal and family responsibilities of employees, and anti-Covid-19 measures at the same time. The model was tested on real data provided by the Department of Mechanical, Energy and Management Engineering at the University of Calabria, Italy. Computational experiments show good performance to ensure work and continuity of activities.

Mehrizi *et al.* [2022] proposed a two-stage mathematical optimization framework for personal scheduling during a pandemic, and demonstrated an application of the framework for a radiation therapy department case study. Their framework considers the probability of infection transmission among potential customers and staff, the effect of interaction between staff members who work in close contact, and the characteristics of the disease such as the incubation period during which customers and staff members can be asymptomatic but infectious. The optimization model determines optimal working patterns that minimize the expected number of staff absences due to interactions. However, the model does not take into account the hours worked by each employee.

Although the experiments carried out by Zucchi *et al.* [2021], Guerriero and Guido [2021] and Mehrizi *et al.* [2022] have shown satisfactory results, to the authors' knowledge, this is the only solution where there is the possibility of maximizing the face-to-face scheduling of staff who work in a hybrid way, alternating face-to-face and remote. Therefore our approach can help companies that need to restrict the number of employees in the same environment, adopt remote periods for part of the team, guarantee a maximum number of face-to-face working hours, or minimize the number of professionals per work shift. Moreover, we emphasize that the proposed approach has been also applied to three different companies, whereas the reference works consider only one company.

3 Proposed MILP framework

In this section, we present a framework based on a mathematical optimization model to generate personal scheduling in pandemic situations. Our objective is to develop a set of constraints that can be flexibly applied to suit different companies' specific requirements. In the proposed framework, a company can run our framework by i) selecting a subset of these constraints, and ii) establishing the input parameters.

In our framework, set E denotes the set of employees, P represents the set of various work periods or shifts, and T represents the set of time intervals in which the scheduling is done. Understanding the connections between sets P and T is crucial for effective scheduling. In our model, P stands for different work periods, including in-person, remote, and various shifts like morning and night. On the other hand, T represents the time intervals for scheduling, like days, weeks, or shifts. We designed this model to be versatile, suitable for various scaling challenges. Similarly, to maintain this adaptability, we afford diverse ways to partition the employee set E. For instance, a common categorization is into E_r (higher-risk employees for remote work) and $E \setminus E_r$ (other employees). However, these partitions can represent various criteria based on specific needs; for instance, employees can be organized into teams, and the set of teams is defined by $\mathcal{S}$, where $\mathcal{S}$ is a subset of the power set of E, denoted as 2^E .

Tables 1 and 2 describe the indices of the decision variables and some parameters that can be used in a company formulation, respectively. We define the decision variables as follows:

- $x^t_{p,e}$: Binary variable that is 1 if employee e works in period p at time t, and 0 otherwise;
- $y^t_{p,e}$: Integer variable that represents the number of hours worked personally by the employee in period p at time t;

Our framework mathematical formulation is defined as follows:

$$
\begin{aligned}
&\text{opt } f(x,y) && && \text{(1a)}\\
&\text{s.t} \sum_{p\in P} x^t_{p,e} = 1 && \forall t \in T, e \in E && \text{(1b)}\\
&\sum_{p\in P}\sum_{t\in T} y^t_{p,e} = H_{max} && \forall e \in E && \text{(1c)}\\
&y^t_{p,e} \le h_{\text{per}} x^t_{p,e} && \forall e \in E, t \in T, p \in P && \text{(1d)}\\
&x^t_{i,e} = 0 && \forall e \in E_r, t \in T && \text{(1e)}\\
&\sum_{e\in E} x^t_{i,e} \le \max\nolimits_{\text{work-per-i}} && \forall t \in T && \text{(1f)}\\
&\sum_{e\in E} x^t_{i,e} \ge \min\nolimits_{\text{work-per-i}} && \forall t \in T && \text{(1g)}\\
&\sum_{t\in T} y^t_{i,e} \ge \min\nolimits_{\text{hours-per-i}} && \forall e \in E \setminus E_r && \text{(1h)}\\
&\sum_{t\in T} y^t_{i,e} \le \max\nolimits_{\text{hours-per-i}} && \forall e \in E \setminus E_r && \text{(1i)}\\
&\sum_{e\in S} x^t_{i,e} \le \max\nolimits_{\text{team-per-i}} && \forall S \in \mathcal{S}, t \in T && \text{(1j)}\\
&\sum_{e\in S} x^t_{i,e} \ge \min\nolimits_{\text{team-per-i}} && \forall S \in \mathcal{S}, t \in T && \text{(1k)}\\
&x^t_{p,e} \in \mathbb{Z}_+ && \forall e \in E, t \in T, p \in P && \text{(1l)}\\
&y^t_{p,e} \in \mathbb{Z}_+ && \forall e \in E, t \in T, p \in P && \text{(1m)}
\end{aligned}
$$

The Objective Function seeks to optimize the criterion chosen by the company. For instance, if the company is interested in maximizing the number of hours worked in-person, it could be formulated as follows:

$$\max \quad \sum_{t\in T}\sum_{e\in E} y^t_{i,e} \tag{2}$$

In the example of equation (2), it is assumed that a period $p = i$ means a face-to-face work period, and $p \neq i$ a remote work period.

Constraints (1b–1e) are responsible for generating the professional's scheduling, ensuring that each employee is allocated to a period while respecting the working hours and the maximum number of employees allowed per period.

Constraints (1b) ensure that each employee e is assigned to exactly one period p at each time t. This guarantees that every employee is scheduled to work during a specific period. Constraints (1c) define the total number of hours worked by each employee e. The parameter H_{max} represents the maximum total hours worked by each employee. Constraints (1d) limit the number of hours worked by an employee e in a single period, ensuring that the total hours worked in a period for each employee are within the allowable limit. The parameter h_{per} represents the allowable maximum number of hours that an employee can work during a single period. Constraints (1e) set the binary variable $x^t_{i,e}$ to 0 for employees that cannot work in period i. It is important to note that period i can be used to designate either a face-to-face period or the night period.

The Constraints (1f–1j) collectively ensure that the work schedules for each employee are appropriately assigned with respect to working hours, maximum and minimum employee requirements per period, and the total number of hours worked while adhering to specific team and time restrictions. These constraints can be applied either for a specific period i or for the entire set of periods P, providing flexibility and adaptability to different organizational requirements and objectives.

Constraint (1f) limits the number of employees assigned to a period i at each time t to a maximum value, controlling the maximum number of employees working during a particular period. Similarly, Constraints (1g) control the minimum number of employees working during a particular period. Constraints (1h) set a minimum requirement for the total number of hours worked by each employee e in a specific period i. Similarly, Constraints (1i) set a maximum requirement for the total number of hours worked by each employee e in the period i. Constraint (1j) ensures that the number of employees assigned to a specific period i in each team S and time t does not exceed a predefined maximum value. Similarly, Constraints (1k) set a minimum requirement for the number of employees assigned to the period i in each team S and time t. Finally, Constraints (1l–1m) define the domains of the variables, specifying that the decision variables must be non-negative integers.

This section has shown a key distinguishing feature of our model compared to existing literature. Unlike previous works, our model introduces the capability to maximize face-to-face scheduling for employees who follow a hybrid work arrangement, involving a combination of in-person and remote work. Furthermore, the flexibility of our framework is worth highlighting, as it can be tailored to accommodate various restrictions and objectives specific to different companies. By incorporating customizable parameters and constraints, our model provides adaptability to address the unique requirements and goals of individual organizations.

Table 1. Index table

Index	Description
p	The working periods. It can vary according to the company and represents the different types or modes of work, such as face-to-face, remote, Morning, Afternoon, Night, etc.
e	Employee index.
t	Time index. It can be defined according to the institution's preference, assuming the values of weeks, days, or shifts.

Table 2. Data Entry Parameters

$Parameters$	**Description**
T	Time set.
E	Set of employees.
E_r	Represents employees who belong to the COVID-19 risk group.
P	Mode of work, it can be interpreted as a collection of time intervals or periods.
$\mathcal{S}$	Set of teams.
H_{max}	The total hours worked by each employee.
h_{per}	The maximum number of hours worked by an employee in a single period.
$\text{min}_{\text{work-per-i}}$	The minimum requirement for the total number of employees working in period i.
$\text{max}_{\text{work-per-i}}$	The maximum requirement for the total number of employees working in period i.
$\text{min}_{\text{hours-per-i}}$	The minimum requirement for the total number of hours worked by each employee in period i.
$\text{max}_{\text{hours-per-i}}$	The maximum requirement for the total number of hours worked by each employee in period i.
$\text{min}_{\text{team-per-i}}$	The minimum requirement for the total number of employees working in period i for each team.
$\text{max}_{\text{team-per-i}}$	The maximum requirement for the total number of employees working in period i for each team.

4 Experimental results

This section reports the computational experiments that were conducted to evaluate the proposed framework. Our experimental platform consists of an Intel i7-1165G7 @ 2.80GHz with 16GB of RAM, and only one core was used to run the experiments. The proposed framework was developed in Python language using the PuLP API and CBC[1] of COIN-OR as mixed integer linear programming solver. We consider three real-world Brazilian companies with different constraints and objectives as case studies: SENAI[2], SENAC[3] and Maceió Shopping[4]. We compared the schedules generated automatically by our framework with those produced manually by these three companies.

4.1 SENAI

SENAI (Serviço Nacional de Aprendizagem Industrial) is one of the most important Brazillian centers for the generation and dissemination of industrial development applied knowledge. This case study focuses on the department of Digital Solutions, which is part of the Innovation Hub from the Regional Department of SENAI Alagoas. This department is responsible for the software development for the educational segment and it has a team of 18 professionals from different areas and backgrounds, including systems analysts, designers, and developers, among others. Divided into work teams, in an ideal scenario, every worker shares the same environment during the workday. From Monday to Friday, the workday consists of eight work hours a day and one hour of break, totaling forty hours of work per week. Thus, the sharing of resources such as computers, tables, chairs, in addition to office supplies, becomes common among teams.

The network of relationships between employees is described in the following manner. There are a total of five analysts (labeled as E1 to E5), seven designers (E6 to E12), and six developers (E13 to E18), each assigned to specific teams. Members of the same team have a strong collaboration, working together in the same workspace simultaneously, highlighting teamwork and resource sharing.

With the emergence of the pandemic caused by COVID-19, the department had to adapt to the distance norms. In

[1] COIN-OR Branch-and-Cut solver: https://github.com/coin-or/Cbc
[2] SENAI Alagoas: https://al.senai.br/
[3] SENAC Alagoas: https://www.al.senac.br/
[4] Maceió Shopping: https://www.maceioshopping.com/

order to allow the continuity of the demands of each team, SENAI was interested in maximizing the face-to-face working hours, while attending the restrictions shown below. Note that, next to each restriction, we refer to the corresponding constraint that will be instantiated from our framework.

(1-a) Each worker is required to work either remotely or face-to-face every day (Constraints (1b)).

(1-b) The total work hours per week for each employee must be exactly 40 hours (Constraints (1c) and (1d)).

(1-c) The maximum number of employees working in a particular week is less than or equal to 10 (Constraints (1f)).

(1-d) Each team must have at least three members working in a particular week (Constraints (1k)).

(1-e) To achieve a balanced distribution of face-to-face work hours among employees, each employee must work a minimum of 80 hours and a maximum of 120 hours in the face-to-face period, considering all the weeks (Constraints (1h) and (1i)).

Table 3 shows the solution adopted by the institution during the Pandemic, where colored cells indicate the weeks an employee must work in-person. The color of a cell highlights employees from the same team. This schedule is periodic, i.e., it repeats itself every two weeks. The solution generated by the company reaches a total of 1360h of the possible 1600h of hours of face-to-face work. It divides the 18 workers into two teams, such that each week one team works in-person and the other works remotely.

Table 3. Face-to-face work schedule manually produced by SENAI Alagoas

Employee	Week 0	Week 1	Weerks per month
E1	(green)		2
E2	(green)		2
E3	(green)		2
E4	(green)		2
E5	(green)		2
E6	(red)		2
E7	(red)		2
E8	(red)		2
E9	(red)		2
E10		(red)	2
E11		(red)	2
E12		(red)	2
E13		(teal)	2
E14		(teal)	2
E15		(teal)	2
E16		(teal)	2
E17		(teal)	2
E18		(teal)	2
# Employees	9	9	

Through the instantiation of the constraints and objective function from our framework, the problem was modeled as follows:

$$\max \sum_{t\in T}\sum_{e\in E} y^t_{1,e} \tag{3a}$$

$$\text{s.t} \sum_{p\in P} x^t_{p,e} = 1 \qquad \forall t\in T, e\in E \tag{3b}$$

$$\sum_{p\in P}\sum_{t\in T} y^t_{p,e} = H_{max} \qquad \forall e\in E \tag{3c}$$

$$y^t_{p,e} \le h_{\text{per}} x^t_{p,e} \qquad \forall e\in E, t\in T, p\in P \tag{3d}$$

$$\sum_{e\in E} x^t_{1,e} \le \text{max}_{\text{work-f2f}} \qquad \forall t\in T \tag{3e}$$

$$\sum_{e\in S} x^t_{1,e} \ge \text{min}_{\text{team-f2f}} \qquad \forall S\in\mathcal{S}, t\in T \tag{3f}$$

$$\sum_{t\in T} y^t_{1,e} \ge \text{min}_{\text{hour-f2f}} \qquad \forall e\in E\setminus E_r \tag{3g}$$

$$\sum_{t\in T} y^t_{1,e} \le \text{max}_{\text{hour-f2f}} \qquad \forall e\in E\setminus E_r \tag{3h}$$

$$x^t_{p,e}\in\{0,1\} \qquad \forall e\in E, t\in T, p\in P \tag{3i}$$

$$y^t_{p,e}\in\mathbb{Z}_+ \qquad \forall e\in E, t\in T, p\in P \tag{3j}$$

Note that Constraints (3b,3c,3d,3e,3f,3g and 3h) are instantiations of the general Constraints (1b,1c,1d,1f,1k,1h and 1i), respectively. We remark that Constraints (1f,1k,1h and 1i) are applied for $i = 1$, i.e., face-to-face period. Table 4 shows the parameter settings for this case study. The time parameter T represents the set of weeks, and P distinguishes between work face-to-face ($p = 1$) and remote ($p = 2$).

Table 4. Parameters for the SENAI problem

Parameter	Value
$\|T\|$	4
$\|E\|$	18
$\|E_R\|$	0
$\|P\|$	2
$\|\mathcal{S}\|$	3
H_{max}	40
$\text{max}_{\text{work-f2f}}$	10
$\text{min}_{\text{team-f2f}}$	3
h_{per}	40
$\text{min}_{\text{hours-f2f}}$	80
$\text{max}_{\text{hours-f2f}}$	120

Table 5 shows the face-to-face work schedule obtained through our framework. This solution respects all 5 constraints demanded by the company, in particular, note: (i) each 'Week' column has no more than 10 colored cells (constraint (1-c)), (ii) each column 'Week' has at least three cells of the same color (constraint (1-d)), and (iii) each employee line 'E' has a maximum of three and a minimum of two colored cells (constraint (1-e)).

Our solution achieved a total of 1600h of the possible 1600h face-to-face work. This result is about 15% better compared to the solution adopted by the company, which had

Table 5. Face-to-face work schedule generated by our framework for the SENAI problem

Employee	Week 0	Week 1	Week 2	Week 3	Weerks per month
E1	green	green			2
E2			green	green	2
E3	green	green	green		3
E4		green	green	green	3
E5	green			green	2
E6			red	red	2
E7	red			red	2
E8	red		red		2
E9	red		red		2
E10	red	red	red		3
E11		red		red	2
E12		red		red	2
E13		teal	teal		2
E14		teal	teal		2
E15	teal			teal	2
E16	teal	teal		teal	3
E17	teal			teal	2
E18		teal	teal		2
# Employees per week	10	10	10	10	

a value of 1360h (Table 3). Our framework obtained this optimal solution in 0.064 seconds.

4.2 SENAC case study

Created in 1946, SENAC is a private law institution subordinated to the National Confederation of Commerce (CNC)[5]. It is one of the main professional education agents focused on the trade of goods, services, and tourism in Brazil.

This case study considered the administrative sector of SENAC Alagoas, which comprises a team of 14 employees divided into two distinct groups. Team 1 consists of employees E1 to E7, while team 2 encompasses employees E8 to E14. The working day is normally divided into two 8-hour shifts, spread between 8:00 and 22:00. A third shift was adopted during the pandemic, modifying the working hours and reallocating some of the employees. In this case study, the company's objective was to minimize the total hours worked during the night shift. The restrictions adopted by the company are given below. As done in the previous case study, next to each restriction, we refer to the corresponding constraint of our framework.

(2-a) Each employee's total daily work hours must be exactly 8 hours in a unique shift, and the total work hours in a week must be 40 hours (Constraints (1b), (1c) and (1d)).

(2-b) Each employee can work a maximum of 8 hours in the night shift in a week (Constraints (1i)).

(2-c) For each team, a maximum of 3 employees are allowed to work during a specific period (Constraints (1j)).

[5]National Confederation of Commerce: https://www.portaldocomercio.org.br/

Considering the constraints from our framework, we modeled the SENAC problem as follows:

$$\min \sum_{e\in E}\sum_{t\in T} y^t_{3,e} \tag{4a}$$

$$\text{s.t} \sum_{p\in P} x^t_{p,e} = 1 \qquad \forall t\in T, e\in E \tag{4b}$$

$$\sum_{p\in P}\sum_{t\in T} y^t_{p,e} = H_{max} \qquad \forall e\in E \tag{4c}$$

$$y^t_{p,e} \leq h_{\text{per}} x^t_{p,e} \qquad \forall e\in E, t\in T, p\in P \tag{4d}$$

$$\sum_{t\in T} y^t_{3,e} \leq \text{max}_{\text{hours-nig}} \qquad \forall e\in E\setminus E_r \tag{4e}$$

$$\sum_{e\in S} x^t_{p,e} \leq \text{max}_{\text{team}} \qquad \forall S\in\mathcal{S}, t\in T, p\in P \tag{4f}$$

$$x^t_{p,e} \in \{0,1\} \qquad \forall e\in E, t\in T, p\in P \tag{4g}$$

$$y^t_{p,e} \in \mathbb{Z}_+ \qquad \forall e\in E, t\in T, p\in P \tag{4h}$$

Note that Constraints (4b, 4c, 4d, 4e and 4f) are instantiations of the general Constraints (1b, 1c, 1d, 1i and 1j), respectively. We remark that Constraints (1j) are applied for all period $p \in P$.

We optimize the weekly schedule minimizing working hours on the night shift. It is important to note that: i) the value $p = 3$ corresponds to the night shift, and ii) for other weeks, the schedule can be obtained by simple rotations of workers. Table 6 and 7 show, respectively, the model parameters and the results obtained through our framework. Each row represents the schedule of an employee for each day and shift, denoted as Morning (M), Afternoon (A), and Night (N).

The solution obtained in Table 7 attends all the three company constraints, while minimizing working hours on the night shift: (i) for each day 'D' column and each employee 'E' row, only one of the three shift cells is colored (constraint (2-a)), (ii) for each employee row, at most one night shift column 'N' is colored (constraint (2-b)), and (iii) for each shift column there are at most three colored cells of the same color (constraint (2-c)). The proposed framework attained the optimal solution in 0.03 seconds. For this case study, the company had not previously devised a work schedule that incorporated the night shift. However, without the night shift, the company had 7 employees working in the same room. With our proposed solution, the maximum number of employees in the same room is reduced to 6, thereby improving the working environment.

Table 6. Parameters for the SENAC problem

Parameter	Value
$\lvert T\rvert$	5
$\lvert E\rvert$	14
$\lvert P\rvert$	3
$\lvert\mathcal{S}\rvert$	2
H_{max}	40
h_{per}	8
$\text{max}_{\text{hours-nig}}$	8
max_{team}	3

Table 7. Work schedule generated by our framework for the SENAC problem

Employees	**D1**			**D2**			**D3**			**D4**			**D5**			**Days per week**
	M	**A**	**N**	**M**	**A**	**N**	**M**	**A**	**N**	**M**	**A**	**N**	**M**	**A**	**N**	
E1																5
E2																5
E3																5
E4																5
E5																5
E6																5
E7																5
E8																5
E9																5
E10																5
E11																5
E12																5
E13																5
E14																5
# Employees per shift	6	6	2	6	6	2	6	6	2	6	6	2	6	6	2	

Table 8. Work schedule manually produced by Maceió Shopping

Employees	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Days per per week**
E1						2–3
E2						2–3
E3						2–3
E4						2–3
E5						2–3
E6						2–3
E7						2–3
E8						2–3
E9						2–3
E10						2–3
E11						2–3
E12						2–3
E13						2–3
E14						2–3
E15						2–3
E16						2–3
E17						2–3
E18						2–3
E19						2–3
E20						2–3
# Employees per week	10	10	10	10	10	

Table 9. Work schedule generated by the our framework for the Maceió Shopping problem: Week 1

Employees	Monday	Tuesday	Wednesday	Thursday	Friday	Days per per week
E1		■	■	■	■	4
E2		■		■		2
E3		■			■	2
E4	■			■		2
E5	■		■	■	■	4
E6	■	■	■	■		4
E7			■	■	■	3
E8		■			■	2
E9						0
E10						0
E11	■	■				2
E12	■	■	■		■	4
E13	■	■	■		■	4
E14	■		■		■	3
E15			■			1
E16						0
E17	■			■	■	3
E18			■	■		2
E19	■	■		■	■	4
E20	■	■	■	■		4
# Employees per week	10	10	10	10	10	

4.3 Case study Maceió Shopping

With thirty-two years of operation and located in one of the most important areas of the capital of Alagoas, Maceió Shopping occupies a prominent position in local and regional retail. It has more than 300 points of sale, offering many products and services. The administration has a total of 30 professionals responsible for its management, among which 20 work in the same environment. The working day is 8 hours a day from Monday to Friday, totaling 40 hours a week. Contact between members became constant and inevitable.

During the pandemic, the following restrictions were adopted by the company:

(3-a) Each worker is required to work either remotely or face-to-face every day (Constraints (1b)).

(3-b) Each employee is required to work exactly 132 hours in total every month (Constraints (1c)).

(3-c) Maceió Shopping sets a maximum limit of 10 employees working face-to-face at any given time (Constraints (1f)).

(3-d) There must be a minimum of 2 employees available for face-to-face work at any given time (Constraints (1g)).

(3-e) Employees in the risk group are exclusively assigned to remote work and are not allowed to work face-to-face (Constraints (1e)).

(3-f) The total hours worked by each employee in a day must not exceed the allowable limit of 6.6 hours (Constraints (1d)).

(3-g) Each employee, excluding those in the risk group or any other exclusion criteria, must work at least 70 hours in the face-to-face period (Constraints (1h)).

(3-h) Additionally, each employee has a limit on the total number of hours worked in the face-to-face period, which cannot exceed 120 hours (Constraints (1i))

Table 8 shows the solution adopted by the institution during the pandemic, which is repeated every two weeks. A colored cell indicates that the employee works 6.6 hours on the corresponding day. In this solution, each person is allocated in-person for two days a week, with an alternating Friday between the work teams. Another important point is that the company generated the work schedule without considering the workers in the risk group, which violates one of its constraints. The company's solution has a total of 924 face-to-face hours.

Given that the company was interested in maximizing the face-to-face working hours, this case study was modeled as follows:

$$\max \sum_{t\in T}\sum_{e\in E} y^t_{1,e} \tag{5a}$$

$$\text{s.t} \sum_{p\in P} x^t_{p,e} = 1 \qquad \forall t \in T, e \in E \tag{5b}$$

$$\sum_{p\in P}\sum_{t\in T} y^t_{p,e} = H_{max} \qquad \forall e \in E \tag{5c}$$

$$\sum_{e\in E} x^t_{1,e} \leq \text{max}_{\text{work-f2f}} \qquad \forall t \in T \tag{5d}$$

$$\sum_{e \in E} x^t_{1,e} \geq \text{min}_{\text{work-f2f}} \qquad \forall t \in T \quad (5e)$$

$$x^t_{1,e} = 0 \qquad \forall e \in E_r, t \in T \quad (5f)$$

$$y^t_{p,e} \leq h_{\text{per}} x^t_{p,e} \qquad \forall e \in E, t \in T, p \in P \quad (5g)$$

$$\sum_{t \in T} y^t_{1,e} \geq \text{min}_{\text{hours-f2f}} \qquad \forall e \in E \setminus E_r \quad (5h)$$

$$\sum_{t \in T} y^t_{1,e} \leq \text{max}_{\text{hours-f2f}} \qquad \forall e \in E \setminus E_r \quad (5i)$$

$$x^t_{p,e} \in \{0,1\} \qquad \forall e \in E, t \in T, p \in P \quad (5j)$$

$$y^t_{p,e} \in \mathbb{Z}_+ \qquad \forall e \in E, t \in T, p \in P \quad (5k)$$

Note that Constraints (5b, 5c, 5d, 5e, 5f, 5g, 5h and 5i) are instantiations of the general Constraints (1b, 1c, 1f, 1g, 1e, 1d, 1h and 1i), respectively. In the described scenario, the time parameter T of our framework is considered the interval of one day. Table 10 shows the parameter settings.

Table 10. Parameters for the Maceió Shopping problem

Parameter	Value
$\|T\|$	20
$\|E\|$	20
$\|E_R\|$	3
$\|P\|$	2
$\|\mathcal{S}\|$	–
H_{max}	132
$\text{max}_{\text{work-f2f}}$	10
$\text{min}_{\text{work-f2f}}$	2
h_{per}	6.6
$\text{min}_{\text{hours-f2f}}$	70
$\text{max}_{\text{hours-f2f}}$	120

Tables 9, 11, 12 and 13 show the in-person weekly working hours generated as a result of the case study, spread over 4 weeks. As shown in these tables, all company constraints are met. In particular, note that: (i) each day column in these tables has a maximum of 10 and a minimum of 2 colored cells (constraints (3-c) and (3-d)), (ii) none of the cells related to employees E9, E10, and E11 are colored (constraint (3-e)), and (iii) except the employees in the risky group, the number of colored cells for all other employees considering all tables is between 11 and 16 (constraints (3-g) and (3-h)).

The results obtained through the presented mathematical model, totaling 1320 face-to-face hours out of the 1320 possible hours. This result indicates a 30% increase in comparison to the company solution, which was 924h. Another point to note is that this optimal solution was found in just 0.47 seconds and, unlike the solution adopted by the company, it does not violate the laughing group constraints.

5 Conclusion

Pandemic outbreaks raise many challenges that can compromise business continuity. Recently, the coronavirus has brought some problems to the personal work schedule. This article presented a framework based on mathematical programming for a personal scheduling problem considering pandemic events. Our framework considers a set of general parameters and MILP restrictions that we select in order to meet the guidelines to reduce the spread of a virus. We applied the proposed approach to three real-life Brazilian companies and compared our results with those produced manually by these companies.

To summarize our findings, Figures 1 and 2 illustrate the monthly face-to-face work hours for each employee based on our solution and the practices adopted by Senai and Maceió Shopping, respectively. In the case of Senai, our solution achieved the maximum of 1600 hours of potential face-to-face work, representing a remarkable 15% improvement over the company's solution, which amounted to 1360 hours. Regarding Maceió Shopping, our mathematical model yielded 1320 face-to-face hours out of a possible 1320 hours, indicating a substantial 30% enhancement compared to the company's practice, which amounted to 924 hours.

The experimental results showed that, in less than two seconds, the proposed framework was able to build a solution that improved the results between 15% and 30%, compared to the solutions generated by the companies. In addition to reducing the risk of contagion in cases of shift redistribution. As future work, we can consider the inclusion of the risk factor of contagion in the objective function. In addition, we can consider the insertion of an emotional factor and the performance preferences of each employee, applying changes in the objective function in order to improve the individual and collective performance of the team.

Declarations

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Authors' Contributions

FOH contributed to Data curation, Investigation, Conceptualization, and Writing — original draft. BN and RGSP contributed to Conceptualization, Methodology, Writing — review & editing, and Supervision. All authors read and approved the final manuscript.

Competing interests

The authors declare no competing interests.

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Table 11. Work schedule generated by the our framework for the Maceió Shopping problem: Week 2

Employees	Monday	Tuesday	Wednesday	Thursday	Friday	Days per per week
E1						2
E2						3
E3						2
E4						3
E5						2
E6						3
E7						3
E8						4
E9						0
E10						0
E11						4
E12						3
E13						1
E14						4
E15						4
E16						0
E17						3
E18						2
E19						4
E20						3
# Employees per week	10	10	10	10	10	

Table 12. Work schedule generated by the our framework for the Maceió Shopping problem: Week 3

Employees	Monday	Tuesday	Wednesday	Thursday	Friday	Days per per week
E1						3
E2						4
E3						4
E4						3
E5						3
E6						4
E7						2
E8						3
E9						0
E10						0
E11						3
E12						2
E13						3
E14						3
E15						2
E16						0
E17						3
E18						5
E19						1
E20						2
# Employees per week	10	10	10	10	10	

Table 13. Work schedule generated by the our framework for the Maceió Shopping problem: Week 4

Employees	Monday	Tuesday	Wednesday	Thursday	Friday	Days per per week
E1		■			■	2
E2	■	■	■	■		4
E3	■		■	■	■	4
E4	■	■			■	3
E5		■	■			2
E6	■	■	■	■	■	5
E7			■	■	■	3
E8	■	■				2
E9						0
E10						0
E11			■		■	2
E12	■		■			2
E13	■			■	■	3
E14	■	■		■		3
E15		■	■	■	■	4
E16						0
E17	■	■		■	■	4
E18	■		■			2
E19			■	■		2
E20		■		■	■	3
# Employees per week	10	10	10	10	10	

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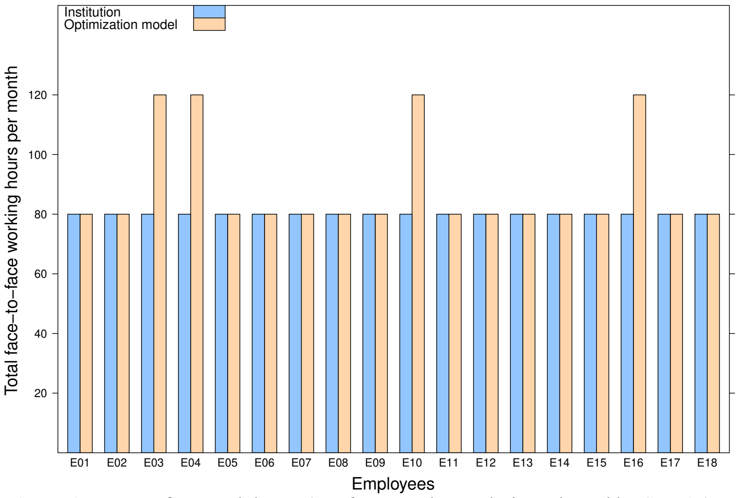

Figure 1. Face-to-face work hours (our framework vs solution adopted by SENAI)

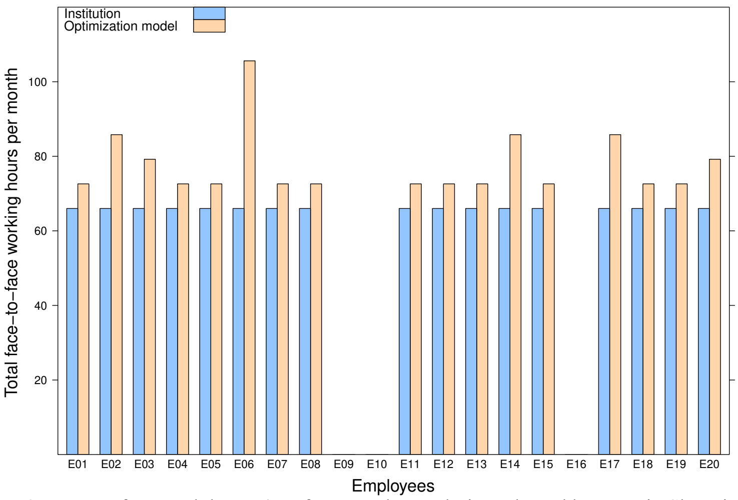

Figure 2. Face-to-face work hours (our framework vs solution adopted by Maceió Shopping)

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