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A mixed-integer linear programming model for scheduling volunteers in technical support teams in Non-Governmental Organizations

Valdir Soares da Silva Neto [1]* - https://orcid.org/0009-0007-8093-5146

Ricardo Lukas de Medeiros França [1] - https://orcid.org/0009-0008-9543-8553

Keren Karolyne Nóbrega Silva [1] - https://orcid.org/0009-0006-9007-2287

Luciano Carlos Azevedo da Costa [1,2] - https://orcid.org/0000-0002-6324-6556

Hugo Harry F. R. Kramer [1,2] - https://orcid.org/0000-0003-4720-7546

[1] Postgraduate Program in Production and Systems Engineering,
Federal University of Paraíba, João Pessoa - PB, Brazil.
Emails: valdir.soares@academico.ufpb.br, ricardo.lukas@academico.ufpb.br, kerenobrega@gmail.com

[2] Department of Production Engineering,
Federal University of Paraíba, João Pessoa - PB, Brazil
Emails: luciano.costa@academico.ufpb.br, hugo.kramer@academico.ufpb.br
* Corresponding author

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Abstract

The problem of allocating scarce resources is present in many daily decisions, at various levels, whether organizational or not. Institutions need to plan in detail how to distribute resources efficiently, especially when it comes to people and their skills and competencies in providing services. In this context, the aim of this study is to determine timetables for the volunteers of a technical support team in a non-governmental organization, considering the individual skills constraints of the volunteers and their respective availability. To solve the problem, a mathematical model is proposed whose objective is to allocate volunteers to tasks for which they have the greatest ability. The model ensures that the technical needs of the team are met, guaranteeing the allocation of specific numbers of volunteers to each role. The model also favors a balanced distribution of work among the volunteers. The results show that the proposed model can find optimal solutions in reduced computational time. The solutions generated by the proposed model are already being implemented and used in practice.

Keywords

allocation of scarce resources, Mixed Integer Linear Programming, timetable, Operations Research.

1. Introduction

Every day organizations face the complex task of making decisions involving a wide range of resources. While some processes may be less complex, others require more in-depth analysis. In this scenario, incorporating optimization tools into the decision-making process is a necessary measure (Mobuss, 2018). Among the challenges inherent in business, the scarcity of resources stands out as a major obstacle, ranging from the availability of labor to the competence of employees, processing time and the investment resources provided.

In complex decision-making situations at the organizational level, Operations Research (OR) offers companies a set of tools to improve their choices, especially those involving resource allocation, competency restrictions and availability of inputs (Vieira, 2022). A classic OR problem is the assignment problem, which can be applied to the distribution of professionals in activities correlated to their skills and availability, thus bringing talent closer to the operations to be carried out. This problem seeks to find a feasible assignment for workers or tasks while respecting the constraints inherent to the problems (Osman, 1995; Oncan, 2017). An example of a problem involving the allocation of scarce resources is the so-called Generalized Allocation Problem (GAP), which was introduced by Ross and Soland (1975). The aim of the GAP is to determine the best allocation of a set of tasks among a group of qualified agents, considering constraints related to limited resources.

The results of applying these optimization problems have been so significant that variations of these concepts continue to be used to this day. The optimization of decisions involving the distribution of resources has been discussed in the literature, focusing especially on the constraints of competencies, the number of resources available and the minimization of failures on the part of employees (Alarcão, 2015; Figueiredo & Pitombeira-Neto, 2017; Szymanski, 2019; Lima, Santos, Teixeira, Lima, & Pitombeira Neto, *2019*). Pires *et al.* (2005) point out that the efficient allocation of employees not only increases the effectiveness of the process, but also improves quality of life at work and institutional commitment. These approaches have been largely applied in government decision-making scenarios and in the allocation of resources in the educational sphere. Resource allocation problems can also be found in the context of management activities in the context of Non-Governmental Organizations (NGOs). In this scenario, these problems are addressed not only for the distributions of tasks, but also to achieve a more effective allocation and distribution of the limited resources available (Teixeira, 2006). Paradela, Lopes and Doro (2021) state that in the process of managing people and allocating assets, one of the main challenges is that the available resources are often not enough to achieve the desired results. Hence, sometimes, one may need to apply methods to obtain high gains in skills allocation performance (Lima et al., 2019).

Based on the above, this study aims to solve an employee allocation problem in an NGO. The approach developed involves the creation of a mathematical programming model that considers constraints related to availability, competence, and desired function. In addition, an attempt is made to thoroughly examine the model developed, highlighting its advantages, disadvantages, and possible implications in the context under analysis. The focus of the research is on the allocation of scarce labor to carry out multimedia activities, considering the availability, skills, and competencies of volunteers.

The structure of the article is as follows: Section 2 discusses works related to the research topic, mentioning examples that can be improved, as well as those used as a reference in the present study. Section 3 presents a detailed description of the problem and the proposed model.

Finally, Sections 4 and 5 present, respectively, the results obtained from the study, the final conclusions of the work, its contributions, and the limitations inherent in the research.

2. Related work

In its classic form, the GAP consists of minimizing the costs of allocating n tasks to a number i of agents, observing the resource limit so that each task is assigned to at least one of the agents. Thus, the allocation problem has wide applicability in various real-world situations and, due to its flexibility, the GAP is often considered a generic way of representing problems in which a resource or entity needs to be allocated to carry out a task. In this way, it can be found in cases for allocating scarce resources, assigning vehicle routes, allocating tasks by skills, allocating storage space, among others. In literature, several authors have explored this class of problem in different contexts. Cattrysse and Van Wassenhove (1992) present a review of studies related to this area, including the study by Fishes and Jaikumar (1981) on the assignment of vehicles to meet demands, the consideration of the *minimax* objectives for the GAP by Mazzola, Neebe and Dunn (1988), Balachandran's (1972) research into the assignment of tasks to networked computers, as well as the assignment of ships for inspection by Gross and Pinkus (1972).

The GAP holds diverse applications within the education sector, particularly in the effective management of limited resources at universities. The GAP has applications involving the allocation of classrooms and the drawing up of timetables, so that an efficient distribution can be made, considering the restrictions related to the scarcity of resources, such as: availability of classrooms, competence, and availability of teachers for specific subjects, among other aspects that can be considered in specific cases. Among the studies reviewed in the literature, we highlight the contributions of Kostso and Steiner (2003), who developed a model for designing timetables for secondary and primary school classes, taking administrative constraints into account. In addition, Goés (2005) created a prototype that uses three algorithms (exact, heuristic, and mixed) to find solutions that meet the individual preferences of each teacher, as well as the pedagogical and operational requirements in the construction of the school timetable. Ferreira, Karas, Polucoski, Ribeiro and Silva (2011) presented two variants of the formulation for assigning teachers to classes. Another interesting study is that of Lara (2007), who proposed a model for allocating teachers in higher education institutions, considering factors relating to subject preference, allocation history, training suitability and hiring status. Constantino, Mendonça Neto and Martelozzi (2009) addressed the problem of grouping students into classes at a public university with 13,000 undergraduate students, to maximize the number of subjects attended. Góes, Costa and Steiner (2010) developed a heuristic approach to solve a timetable/class scheduling model. Andrade, Scarpin and Steiner (2012) apply a model to generate the timetable courses. Wendt and Muller (2017) applied the assignment model to allocate subjects in classrooms considering timetables and teachers already assigned. Kripka, Kripka and Silva (2011) tackle this problem by seeking to minimize student movements around the campus, i.e. to accommodate them in nearby rooms. Cirino, Sales Müller and de Oliveira (2014) developed a mathematical model with the aim of minimizing the ratio between classroom capacity and demand, as well as considering the shortest distance between the classrooms and the teacher's department, among other constraints. Similarly, Alarcão (2015)'s aim to allocate classes to rooms, respecting the requirements established by each teacher. Cirino (2016) proposed an approach involving exact methods, mono-objective meta-heuristic methods, and a multi-objective method. The latter has a neighborhood structure that obtained results compared to exact methods for a fixed execution time. Santana, Otomo, Shima and Munari (2022) proposed a solution method that decomposes the problem into daily shifts, in addition to a mathematical model, which only considers the classes offered in a shift. The model also considers criteria such as room occupancy, movement of teachers and students, accessibility requirements, for example.

Other applications involve the consideration of the skills of the agents involved in carrying out the tasks. Such as the research by De Andrade Júnior, Reis, Bittencourt, Neves and de Assis Reis (2016), with the aim of maximizing the allocated competences, considering the classification of instructors' competences and the occurrence of simultaneous subjects. Szymanski's work (2019) uses GAP to allocate teams based on competencies, considering the dimensions of worker, region, and competency. Souza (2019) developed a generic methodology for allocating civil servants in public education institutions, in which employees were assigned according to their skills, to optimize the students' learning process. In another study, Figueiredo and Pitombeira-Neto (2017) devised a method based on linear programming to determine the work schedule at a fuel distributor. In this study, they not only improved fuel distribution operations, but also minimized labor-related costs. Another application based on GAP was carried out by Szymanski (2019), who developed and applied a model to solve the problem of allocating teams based on competencies, in the context of a service provider company. Soares, Alves, and Souza (2023) proposed an algorithm for allocating tasks to public auditors. The selection of activities carried out by the auditors focused on those of an operational nature, to develop an algorithm that minimizes the work execution time based on the hours each employee performs these tasks.

Given the above, our study aims at determining the best assignment for a group of voluntary professionals, considering their skills profile and the demand for these skills. Based on applications in the literature, this study aims to propose a mathematical programming model for allocating scarce resources and distributing volunteer labor for activities involving technical support staff focused on multimedia.

3. Problem of building a schedule for volunteers in a multimedia team

In this section we provide a detailed description of the problem being studied as well as present the mathematical model used to solve the problem.

3.1. Characterization of the Problem

In a specific NGO, the multimedia team plays a fundamental role during events since it is responsible for the transmission of events and controlling digital media displays. Computers are employed to manipulate electronic equipment, manage video cameras, and direct the editing of images for online transmission. The team's responsibilities consist of performing the following activities: camera operator, image cutting, mapping operator, and data show operator. The volunteers assigned to the camera role operate video cameras to capture images. The individual in the cutting function selects which camera image will be transmitted. The mapping operator controls projection equipment, determining that will be projected, including available images, or allowing the reproduction of media sent by the volunteer in the data show function. Finally, the data show operator is responsible for reproducing and sending the media to be displayed during the event, including pre-prepared texts, audios, or videos, to be presented at the appropriate time.

The multimedia team covers regular events on Saturdays and, for this purpose, needs an image director who, in addition to cutting the images, takes the lead during the event as coordinator. A volunteer is also needed for the mapping function and another for the data show function. There are six cameras available, requiring the use of at least three during events. In cases of external events, responsibility is transferred to an external team, and the internal team is relieved of their duties on the day in question. The external team is not addressed in this study. For internal or external cases, volunteers in this sector need to meet minimum institutional and training requirements to carry out their activities. After this phase, the participant is expected to follow the execution of the function for at least two days to acquire practical experience. However, it is important to note that the role of coordinator requires knowledge and experience in all functions, as well as the ability to deal with possible technical problems, not forgetting leadership skills during the event.

The complexity of scheduling volunteers is related to the nature of volunteer work, which involves a constant flow of new volunteers in and out. This means that the number of volunteers available one month may be different from another. In addition, volunteers have different skills to carry out the activities, i.e. they are not able to perform all the functions, as is the availability of each volunteer. Taking this variability into account, schedules are drawn up monthly. Each month, volunteers fill in a form stating their availability and the activities they wish to perform. Considering the characteristics of the team, the following restrictions must be respected:

- Each volunteer must perform the service at least once a month.
- Each volunteer can only carry out the service a maximum of the number of times they have informed us when filling in the form.
- Each volunteer can only perform one function at a time each day.
- Each function requires a minimum and maximum number of volunteers to be carried out.

The problem therefore consists of designing a monthly schedule of volunteer services, assigning volunteers to carry out activities and defining a maximum number of times they can work during the period. In addition, it is necessary for each volunteer to choose the role they prefer to perform, as well as a second option, and specify which days they are available to volunteer. As this is voluntary work, achieving an equal distribution of the workload is an important aspect, and attention must be paid to the number of times each volunteer is assigned to the roster. Thus, there must be a balance in the number of times the volunteer is assigned to the roster. Ideally, a volunteer will only be always on the roster if, and only if, it is necessary for the roster to be viable.

3.2. Mathematical Model

Let $I = \{1, \ldots, v\}$ a set of v volunteers to be assigned to perform f functions in $J = \{1, \ldots, f\}$ over a planning horizon $T = \{1, \ldots, s\}$ of periods. For each volunteer $i \in I$, we define total availability $dispt_i$, which corresponds to the maximum number of times a volunteer can be allocated over the planning horizon. In turn, $dispd_{it}$ indicates the availability of each volunteer in each period $t \in T$, where 1 indicates availability and 0 indicates unavailability. In addition, a matrix of H_{it} of allocation possibilities is defined, where the value 1 is assigned if the volunteer can be allocated to the role and zero otherwise. The P_{it} of allocation weights defines the benefit of a volunteer i performing a function j. In this case, P_{it} takes the value 10 if the assigned volunteer i is assigned to perform their main function, the value 1 if they are assigned to perform a secondary function, or 0 if they are assigned to perform the other functions. For each role $j \in J$, the minimum and maximum number of volunteers required is entered, respectively Ne_j e Nm_j.

Let x_{itj} binary variables that take the value 1 if the volunteer i is assigned to the job j in the period t. In turn, let y_i be the number of times volunteer i has been assigned to a role on the scale. Let p be the value of the penalty for each allocation assigned a value of 5. The model proposed for the scale is as follows:

$$Max \sum_{i \in I} \sum_{t \in T} \sum_{j \in J} P_{ij} x_{itj} - py - \sum_{i \in I} \sum_{t \in T} k_{it} \quad (1)$$

Subject to

$$\sum_{t \in T} \sum_{j \in J} x_{itj} \leq dispt_i \quad \forall i \in I \quad (2)$$

$$\sum_{t \in T} \sum_{j \in J} x_{itj} \geq 1 \quad \forall i \in I \quad (3)$$

$$\sum_{j \in J} x_{itj} \leq 1 \quad \forall i \in I, t \in T \quad (4)$$

$$\sum_{i \in I} \sum_{t \in T} x_{itj} \geq Ne_j \quad \forall t \in T, j \in J \quad (5)$$

$$\sum_{i \in I} \sum_{t \in T} x_{itj} \leq Nm_j \quad \forall t \in T, j \in J \quad (6)$$

$$x_{itj} \leq H_{ij}\, dispd_{it} \quad \forall i \in I, t \in T, j \in J \quad (7)$$

$$\sum_{i \in I} \sum_{t \in T} \sum_{j \in J} x_{itj} \leq y \quad (8)$$

$$\sum_{j \in J} x_{itj} + \sum_{j \in J} x_{it+1j} \leq 1 + k_{it} \quad \forall i \in I, t \in T-1 \quad (9)$$

$$x \in \{0,1\} \quad \forall i \in I, t \in T, j \in J \quad (10)$$

$$y \geq 0 \quad (11)$$

$$\mathrm{k} \in \{0,1\} \quad \forall i \in I, t \in T \quad (12)$$

Objective Function (1) aims to maximize the sum of the allocation weights, considering the allocation preference for the main function and subtracting the value of the penalty for the number of times a person is allocated and the penalty for allocating a volunteer in subsequent weeks. Constraints (2) and (3) impose maximum and minimum limits on the number of times a volunteer can be assigned over the horizon. Constraints (4) limit a volunteer to being assigned no more than once per period. Constraints (5) and (6) impose, respectively, the maximum and minimum number of volunteers required per role. Constraints (7) impose that a volunteer can only be assigned to a role if they are able to perform it and are available for assignment in the period. Constraints (8) count the number of times the volunteer i has been assigned in the schedule. Constraints (9) impose a penalty on the objective function if a volunteer is assigned to adjacent weeks. Finally, Constraints (10), (11) and (12) define the domain of the decision variables.

4. Results and Discussion

To assess the model's scalability, it was implemented using the Julia programming language, version 1.8.5, together with the JuMP mathematical programming package, version 1.10.0. The implementation was done in the Visual Studio Code editor and the solution was obtained using the Gurobi optimization software, version 10.0.0. The tests were carried out on a computer with a 2.3 GHz AMD® Ryzen® 7-3700 processor and 12 GB of RAM. The operating system used was Windows 10 Home.

In the study, a case study was carried out using the mathematical model to build a roster for one of the association's teams in a real scenario. The team is made up of volunteers who work on Saturdays and are responsible for broadcasting events and controlling the audiovisual equipment during these events. Due to their voluntary nature, the number of volunteers is subject to constant change, either due to new volunteers joining, some leaving or simply due to changes in their availability. To carry out the experiments, we used data from the scale for the months of May to August 2023. To build the roster, volunteers filled in a form stating their job preferences, total availability, and which Saturdays they would be available. The number of Saturdays on which the team had to perform its role, as well as the number of volunteers in the team for those months, is shown in Table 1. The scale was drawn up for a team with 4 roles, with the minimum number of volunteers per role being [1 1 1 3] and the maximum [1 1 1 6].

Table 1: Number of volunteers and Saturdays per month.

Month	No. of Volunteers	No. of Saturdays
May	16	4
June	22	3
July	21	5
August	23	4

The data relating to the total number of volunteers available per month, the availability per volunteer to work on a given weekend, as well as the indication of whether a volunteer can be allocated to a given role and the weight of these allocations, for the months of May - August / 2023 are detailed in Appendix 1. The data is obtained using a spreadsheet that has already been automated to receive the information from the form. To assess the effectiveness of the proposed method, the solution obtained was compared with the manual solution generated by the team leader, who was responsible for organizing the tables before the model was implemented.

4.1. Implementation of the Proposed Model

Tables 2, 3, 4, 5 and 6 show the timetables for the months of May to August 2013 resulting from the manual solution, as well as the formulation solution. The dates on which the events will take place are shown, along with the roles assigned to each volunteer. To facilitate the process and improve presentation, names have been replaced by numbers in the representation of the solution and in the appendix, so that the number is assigned in the order in which the form was filled in. Thus, the manual scales (tables) went through a verification procedure to identify possible errors that would make the scale (tables) unfeasible. If any unfeasibility was found, a modification process was carried out to make it viable. In this way, the manual tables presented are the tables after the corrections.

Table 2: May Timetable.

Manual Table				Formulation Table			
May 6th	May 13th	May 20th	May 27th	May 6th	May 13th	May 20th	May 27th
COORDINATION	COORDINATION	COORDINATION	COORDINATION	COORDINATION	COORDINATION	COORDINATION	COORDINATION
1	3	2	7	1	3	1	2
MAPPING	MAPPING	MAPPING	MAPPING	MAPPING	MAPPING	MAPPING	MAPPING
8	13	1	14	8	13	8	14
DATA SHOW	DATA SHOW	DATA SHOW	DATA SHOW	DATA SHOW	DATA SHOW	DATA SHOW	DATA SHOW
11	4	2	10	1	11	4	10
CAMERAS	CAMERAS	CAMERAS	CAMERAS	CAMERAS	CAMERAS	CAMERAS	CAMERAS
5	6	4	3	5	6	5	9
7	9	5	9	7	9	7	15
12	16	12	15	12	16	12	16

Table 3: June Timetable.

Manual Table			Formulation Table		
June 3rd	June 17th	June 24th	June 3rd	June 17th	June 24th
COORDINATION	COORDINATION	COORDINATION	COORDINATION	COORDINATION	COORDINATION
3	7	15	3	15	7
MAPPING	MAPPING	MAPPING	MAPPING	MAPPING	MAPPING
11	11	1	11	12	1
DATA SHOW	DATA SHOW	DATA SHOW	DATA SHOW	DATA SHOW	DATA SHOW
10	6	17	10	5	17
CAMERAS	CAMERAS	CAMERAS	CAMERAS	CAMERAS	CAMERAS
2	8	4	2	6	4
5	12	22	9	13	8
18	13	14	14	16	20
19	16	20	18	21	
9	21		19	22	

Table 4: Formulation July Table.

July 1st	July 8th	July 15th	July 22nd	July 29th
COORDINATION	COORDINATION	COORDINATION	COORDINATION	COORDINATION
1	12	4	12	8
MAPPING	MAPPING	MAPPING	MAPPING	MAPPING
14	18	14	18	21
DATA SHOW	DATA SHOW	DATA SHOW	DATA SHOW	DATA SHOW
6	2	5	9	19
CAMERAS	CAMERAS	CAMERAS	CAMERAS	CAMERAS
3	10	1	3	13
7	15	11	10	15
16	20	13	20	17

Table 5: Manual July Table.

July 1st	July 8th	July 15th	July 22nd	July 29th
COORDINATION	COORDINATION	COORDINATION	COORDINATION	COORDINATION
1	4	8	12	1
MAPPING	MAPPING	MAPPING	MAPPING	MAPPING
8	18	14	18	21
DATA SHOW	DATA SHOW	DATA SHOW	DATA SHOW	DATA SHOW
6	2	5	9	19
CAMERAS	CAMERAS	CAMERAS	CAMERAS	CAMERAS
2	3	9	3	11
7	15	11	10	15
16	20	13	13	17

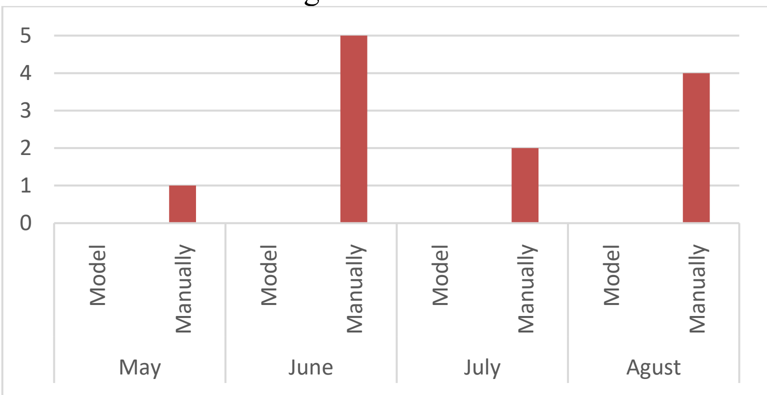
Table 6: August Timetable.

Manual Table				Formulation Table			
August 5th	August 12th	August 19th	August 26th	August 5th	August 12th	August 19th	August 26th
COORDINATION	COORDINATION	COORDINATION	COORDINATION	COORDINATION	COORDINATION	COORDINATION	COORDINATION
15	18	15	1	15	18	1	13
MAPPING	MAPPING	MAPPING	MAPPING	MAPPING	MAPPING	MAPPING	MAPPING
13	4	1	21	13	9	20	4
DATA SHOW	DATA SHOW	DATA SHOW	DATA SHOW	DATA SHOW	DATA SHOW	DATA SHOW	DATA SHOW
8	12	2	7	8	12	2	21
CAMERAS	CAMERAS	CAMERAS	CAMERAS	CAMERAS	CAMERAS	CAMERAS	CAMERAS
16	5	14	10	16	5	10	3
19	6	20	11	16	6	11	6
22	7	3	3	23	17 22	14	16
	17	23	9				

4.2. Model Validation

The model validation process occurred in three stages. In the first stage, the validity of the solutions was verified. At this stage, the solutions obtained were evaluated to identify possible errors. These errors consist of infeasibility in the solutions, which are decisions that do not respect the restrictions related to the problem. Figure 1 illustrates the number of infeasibilities associated with the solutions obtained manually and using the model. The model solution did not present any infeasibility. The fact that infeasibility was only identified in manual solutions highlights that these solutions are susceptible to errors such as allocation of volunteers to more than one function on the same day, failure to allocate at least one volunteer once and allocation of a volunteer several times greater than their availability, among others.

Figure 1: Number of infeasibilities associated with solutions obtained manually and through the model.



The second stage aimed at assessing the performance of the solutions obtained by the model in comparison with manual results. The following metrics were evaluated: value of the objective function of each solution, value of the benefit of the solution, time needed to obtain them and total time (as shown in Table 7). The total benefit corresponds to the value of the objective function without the penalty related to the imbalance of the solution. The total time is the sum of the solution time and the correction time. The correction time refers to the time needed to make the solution feasible in face of unfeasibility. It is important to note that correction time was only necessary for solutions found manually. For the months of May, June, July, and August, respectively, the correction times were 2'21", 1', 1'21" and 6'02". Some corrections were trivial, as in the manual solution for the month of June, which took 1 minute to correct 5 errors, while others were complex, as in the month of August, where the correction took almost half the time needed to build the scale.

Table 7: Manual scale and model scale comparison.

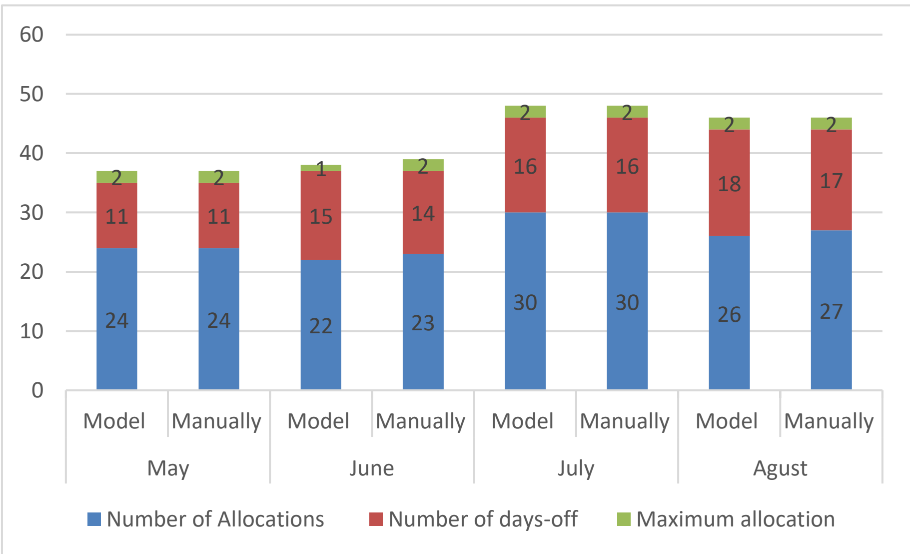
	May		June		July		August	
	Model	Manual	Model	Manual	Model	Manual	Model	Manual
Objective function value	-18	-55	-36	-59	-36	-56	-36	-45
Total benefit	222	195	184	176	264	264	224	225
Time	15"	14'32"	15"	11'14"	18"	17'32"	18"	13'03"
Total Time	15"	16'53"	15"	12'32"	18"	18'53"	18"	19'05"

The model was capable of consistently finding optimal solutions for the solved instances. In contrast, except for the month of August, the manual solutions presented objective function and total benefit values lower than the solution found by the model. In August, the manual solution yielded a benefit greater than that associated with the solution obtained model. However, a lower objective function value was associated. In July, both approaches presented equal values for the benefit, but the solution obtained by the model presented a superior objective function. Regarding the computation time, the model was capable of finding optimal solutions in less than 40 seconds for all months, while the manual approach always required more than 10 minutes to generate solutions. This represents a significant difference, showing the model's ability to generate quality solutions in reduced computational times.

Finally, the third stage consisted of comparing the quality and balance of the solutions. At this stage, the following metrics were considered: number of allocations, number of days-off and maximum allocation (Figure 2). The number of days off indicates how often volunteers were not allocated, despite being available for allocation. The maximum allocation represents the greatest number of times a single volunteer has been allocated. The higher this value, the more unbalanced the solution.

The quality of the model's solutions was always equal to or better than manual solutions in every month. The model was capable of finding some solutions with a smaller number of allocations, which implies a larger number of days off. In June, for example, the model produced a solution where all volunteers were allocated only once, as opposed to the manual solution, which allocated a volunteer more than once. The model not only found the best values with respect to the objective function, but also generated more balanced solutions. This can be justified by the number of days off, which for the solutions found by the model were higher than or equal to the solutions obtained manually. In this way, the model found solutions with more days off and greater balance between allocations, fulfilling the objective of having equal allocations. Even if the solutions obtained manually and by the model may present similar balance metrics, the metrics associated with the quality of the solutions were always better for the solutions obtained by the model (Table 7). This shows that, although the manual method can find satisfactory and balanced solutions, the model demonstrates a unique ability to provide solutions of equal quality in terms of balance, but with a more efficient allocation of volunteers. Furthermore, we point out that the model always generates feasible solution in reduced computation times.

Figure 2: Characterization of allocations



5. Final Considerations

The main contribution of this work was the presentation of a model capable of finding viable solutions in a low computational time for a problem of building work scales. The time required was much less than the time needed to carry out the task manually, eliminating the possibility of failures and rework. Although it was used to create a monthly schedule with one activity per week, the model is applicable to schedules with any frequency of activity. However, it is important to mention that this work has some limitations. The computational tests considered few instances, and these instances can be considered easy, as it was possible to find manually validated solutions in a reasonable amount of time which limited our ability to assess the model's efficiency in more complex scenarios. Regarding the practical implementation of the model, other limitations can be pointed out. One example is the delay in volunteers to fill in the form. Answers often arrive after the release of the month's schedule. Another impactful factor is the communication of absences and replacement requests, which often occurs at critical and last-minute moments. Therefore, future works could explore the application of the model to instances with different levels of difficulty and sizes. Furthermore, the model could also be extended to consider perturbations (absents) in the solution. The model presented is already being widely used by the team and is considered extremely important by the leaders. The volunteers are satisfied with the scales generated by the formulation. There is even a request to create an application that would allow other teams to use the formulation, without the need for technical programming knowledge. This would increase access to and use of the model by people of different profiles.

Conflict of Interest Declaration

The authors have no conflicts of interest to declare.

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Appendix

Data May 2023

Volunteer	Total Individual Availability	Weekly availability				Aptitude				Allocation Weight			
		Saturday 1	Saturday 2	Saturday 3	Saturday 4	Function 1	Function 2	Function 3	Function 4	Function 1	Function 2	Function 3	Function 4
1	3	1	1	1	1	1	1	0	0	10	1	0	0
2	2	1	1	0	1	1	0	1	0	10	0	1	0
3	2	0	1	0	1	1	0	0	1	10	0	0	1
4	2	1	1	1	1	0	0	1	1	0	0	10	1
5	4	1	1	1	1	0	0	1	1	0	0	1	10
6	1	0	1	0	0	0	0	1	1	0	0	1	10
7	4	1	1	1	1	1	0	0	1	10	0	0	1
8	2	1	0	1	0	0	1	0	1	0	10	0	1
9	2	0	1	0	1	0	0	0	1	0	0	0	10
10	1	0	0	0	1	0	0	1	0	0	0	10	0
11	2	1	1	0	0	0	0	1	1	0	0	10	1
12	2	1	1	1	1	0	0	0	1	0	0	0	10
13	2	0	1	0	1	0	1	1	0	0	10	1	0
14	2	0	1	0	1	0	1	1	0	0	10	1	0
15	1	0	0	0	1	0	0	1	1	0	0	1	10
16	3	0	1	0	1	0	0	0	1	0	0	0	10

Data June 2023

Volunteer	Total Individual Availability	Weekly availability			Aptitude				Allocation Weight			
		Saturday 1	Saturday 2	Saturday 3	Function 1	Function 2	Function 3	Function 4	Function 1	Function 2	Function 3	Function 4
1	2	0	1	1	1	1	0	0	10	1	0	0
2	1	1	0	0	0	0	1	1	0	0	10	1
3	3	1	1	1	1	0	0	1	10	0	0	1
4	2	1	0	1	0	0	1	1	0	0	1	10
5	2	1	1	0	0	0	1	1	0	0	10	1
6	2	1	1	0	0	0	1	1	0	0	1	10
7	3	1	1	1	1	0	1	0	10	0	1	0
8	1	0	1	1	0	1	0	1	0	1	0	10
9	3	1	1	1	0	0	0	1	0	0	0	10
10	1	1	0	0	0	0	1	0	0	0	10	0
11	2	1	1	0	0	1	0	0	0	10	0	0
12	1	0	1	0	0	1	0	1	0	1	0	10
13	1	0	1	0	0	0	0	1	0	0	0	10
14	2	1	1	1	0	0	0	1	0	0	0	10
15	1	0	1	0	1	0	0	1	10	0	0	1
16	2	1	1	0	0	0	0	1	0	0	0	10
17	1	0	0	1	0	1	1	0	0	1	10	0
18	1	1	0	0	0	0	0	1	0	0	0	10
19	1	1	0	0	0	0	1	1	0	0	10	1
20	2	0	1	1	0	0	0	1	0	0	0	10
21	1	0	1	0	0	0	0	1	0	0	0	10
22	2	0	1	1	0	0	0	1	0	0	0	10

Data July 2023

Volunteer	Total Individual Availability	Weekly availability					Aptitude				Allocation Weight			
		Saturday 1	Saturday 2	Saturday 3	Saturday 4	Saturday 5	Function 1	Function 2	Function 3	Function 4	Function 1	Function 2	Function 3	Function 4
1	5	1	1	1	1	1	1	0	0	1	10	0	0	1
2	2	1	1	0	0	0	0	0	1	1	0	0	1	10
3	3	1	1	1	1	1	0	0	0	1	0	0	0	10
4	3	0	1	1	0	1	1	0	1	0	10	0	1	0
5	2	1	0	1	0	0	0	0	1	0	0	0	10	0
6	1	1	0	0	0	0	0	0	1	0	0	0	10	0
7	1	1	0	0	0	0	0	0	1	1	0	0	1	10
8	3	1	0	1	1	1	1	1	0	0	10	1	0	0
9	3	0	0	1	1	1	0	0	1	1	0	0	1	10
10	3	0	1	1	1	0	0	0	0	1	0	0	0	10
11	3	1	1	1	1	1	0	0	0	1	0	0	0	10
12	2	0	1	0	1	0	1	0	0	1	10	0	0	1
13	3	0	0	1	1	1	0	0	1	1	0	0	1	10
14	2	1	0	1	0	0	0	1	0	1	0	10	0	1
15	2	0	1	0	0	1	0	0	0	1	0	0	0	10
16	1	1	0	0	0	0	0	0	0	1	0	0	0	10
17	1	0	0	0	0	1	0	1	0	1	0	1	0	10
18	2	0	1	0	1	0	0	1	0	1	0	10	0	1
19	1	0	0	0	0	1	0	0	1	0	0	0	10	0
20	2	0	1	0	1	0	0	0	0	1	0	0	0	10
21	1	0	0	0	0	1	0	1	1	0	0	1	10	0

Data August 2023

Volunteer	Individual Total Availability	Weekly availability				Aptitude				Allocation Weight			
		Saturday 1	Saturday 2	Saturday 3	Saturday 4	Function 1	Function 2	Function 3	Function 4	Function 1	Function 2	Function 3	Function 4
1	3	0	1	1	1	1	1	1	1	10	1	1	1
2	1	0	0	1	0	0	0	1	0	0	0	10	0
3	2	0	0	1	1	0	0	0	1	0	0	0	10
4	2	0	1	0	1	0	1	0	0	0	10	0	0
5	1	0	1	0	0	0	0	0	1	0	0	0	10
6	2	0	1	0	1	0	0	0	1	0	0	0	10
7	2	0	1	1	1	0	0	1	1	0	0	1	10
8	2	1	0	1	0	0	0	1	0	0	0	10	0
9	2	0	1	0	1	0	1	0	1	0	10	0	1
10	2	0	0	1	1	0	0	0	1	0	0	0	10
11	2	0	0	1	1	0	0	0	1	0	0	0	10
12	1	0	1	1	0	0	0	1	1	0	0	10	1
13	4	1	1	1	1	1	1	1	1	10	1	1	1
14	1	0	0	1	0	0	0	0	1	0	0	0	10
15	2	1	0	1	0	1	0	0	1	10	0	0	1
16	3	1	0	1	1	0	0	0	1	0	0	0	10
17	2	0	1	1	0	0	0	1	1	0	0	10	1
18	2	0	1	0	1	1	1	1	1	10	1	1	1
19	2	1	1	1	1	0	0	0	1	0	0	0	10
20	1	0	0	1	0	0	1	0	1	0	1	0	10
21	1	0	0	0	1	0	1	1	0	0	10	1	0
22	2	1	1	0	0	0	0	0	1	0	0	0	10
23	2	1	0	1	0	0	0	0	1	0	0	0	10