Short Paper

A Mathematical Programming Approach for Determining the Fixture of the Kids' Carnival Competition in Uruguay

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ABSTRACT

We present an application of quantitative methods for scheduling the carnival competition of children and teenagers held annually in Uruguay. A mixed-integer linear programming model was developed for the problem, with the aim of finding a fixture that leads to balanced attendance of the public, while fulfilling certain constraints related to the competition regulations and other requirements indicated by the organizers. The fixture obtained from solving the model with an optimization solver was employed in the 2019/2020 edition of the competition, with satisfactory results.

KEYWORDS

fixture of artistic competitions, mathematical programming, scheduling, optimization.

1 INTRODUCTION

The Carnival celebration in Uruguay is the most popular event in the country and considered to be the longest one in the world. Every year, from late December to first days of March, people enjoys street parades and shows all across the country, mainly in the capital city, Montevideo [11] [14].

The Carnival of Promises contest, which emerged more than three decades ago, is held annually in Montevideo between December and January. It is organized by the Department of Culture of the Municipality of Montevideo together with the Association of Directors of the Carnival of Promises (ADICAPRO), a civil society (or NGO) formed around the different artistic groups involved in the contest. Currently, nearby 2,000 children and teenagers from 5 to 18 years old participate in the competition, as can be appreciated in Fig. 1. The organizers promote the social inclusion and integration of children and young people, as well as their artistic, personal and cultural development. In this way, throughout the year, many workshops are carried out that include activities related to music, singing, choreography, dance, acting, makeup, costumes and set design [1].

The competition is ruled by certain guidelines, which are detailed in [3]. The five artistic categories that are represented in the contest are: "murgas", "societies of lubolos", "humorists", "parodists" and "magazines". Each of them can involve dozens of participants on stage, as well as technicians for the design and implementation of the show. The competition is organized in two rounds of ten stages (one stage per day). Each artistic group participates once per round and a maximum of four groups of different categories compete in each stage in different time slots. The closing show of each daily stage is reserved for those groups which won the competition during the previous year and for those which have more public recognition, in order to entice the audience to stay until the end of the stage. On the other hand, the groups that open a stage are usually those who are making their competition debut. Each group only opens a stage at most once during the competition. Scheduling the second round is the most challenging part for those in charge of making the competition fixture, due to certain restrictions to consider regarding the first round. For example, no pair of groups acting at the same stage in the first round can act at the same stage in the second round. Moreover, to ensure a fair competition, all groups should have the same preparation time between both rounds. So, the difference in days between the participation of a group in the first and second rounds must be considered.

The schedule for the Carnival of Promises competition has always been done manually. For this task, some of the organizers dedicate many hours of work over many days, with the aim of determining a two-round schedule considering the aforementioned considerations and some others, as much as possible. Despite the dedicated effort, often the obtained fixture does not meet all the expectations of the participants, as indicated in [7] for the official senior competition. In addition, when a last-minute problem arises, there is not enough time to determine a good quality alternative. With the aim of improving and shortening the process of making the competition schedule, we developed a mixed-integer linear programming model for obtaining a schedule with a balanced attendance of the public at each stage and considering the problem constraints simultaneously.

The rest of document is organized as follows: in Section 2 a brief literature review about related problems is presented; in Section 3 the mathematical model is described; Section 4 includes the analysis of the results obtained through the mathematical model; Sections 5 provides the conclusions and some suggestions for future research.

2 LITERATURE REVIEW

Sport competitions often involve millions of followers and considerable investment in players, broadcasting rights, merchandise, and advertising [15] [9]. This is why there are opportunities to optimize the benefits of the different stakeholders involved and minimize costs or the distances traveled by teams. Therefore, schedules are important to maximize profits and maintain media

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Figure 1: “Revista Fenix” acting in December 2019.

and fan interest. Finding the best schedule for a sports league or championship is a task that requires balancing the interests of different stakeholders and complying with the regulations of each league. For instance, the problem of obtaining the fixture for the Chilean First Division Soccer Championship is tackled in [10]. In [6], a recent survey is provided, considering different problems of sports scheduling, how to solve them and the results obtained for real-world cases, with special focus on Latin America competitions. The impact of match cancellations on the schedules for different football leagues in Europe, due to unforeseen events, is analyzed in [16]. The study carried out by the authors reveals a significant impact on the quality of the schedules obtained after the cancellation of any of the dates of the initial schedule. Several proactive and reactive approaches in order to mitigate this problem are suggested and evaluated.

Regarding artistic competitions, the number of works in the literature is rather scarce. Ortega et al. [12] address a decision-making problem related to the planning of cultural shows in Spain, considering where and when each event will take place. For this, they take into account the points of view of various decision makers involved in the process. The main difference between the problem addressed and other allocation problems, is the maximization of social welfare. The places of performance, the day of performance, costs and budgets are considered. The authors show that the exact solution of the proposed model is difficult to obtain, even for medium-sized cases. To deal with this problem, they suggest an alternative solving approach, in which good approximate solutions are reached. Bikakis et al. [2] consider the problem of assigning artistic events to time intervals to maximize attendance. The objective is to maximize the total profit of the fixture, which is calculated considering the expected attendance for all scheduled events. The authors note that in those cases where the model is highly constrained, it is not possible to find a feasible solution.

We note that there are many works in the literature related to scheduling or allocation problems. Even if these works are not closely related to the problem tackled in this paper, they still contribute to a better understanding of our problem. For instance, Prino et al. [13] consider the problem of assigning households to the members of a cooperative according to their preferences and Bollapragada et al. [4] address the problem of scheduling television commercials.

After a detailed search of the literature, we have not found publications tackling a problem with the same characteristics as the one addressed here. The problem discussed by Ortega et al. [12] considers various stakeholders’ viewpoints and the objective is related to the social welfare; however, their problem consists in assigning sites and days to shows, while in our case we assign artistic groups to time slots in a single site over several days. Another difference is that our problem is about a competition. In [2] different shows (festivals, conferences or parties) must be scheduled, considering that other shows can affect those to be programmed. In our case, the aim is to schedule the performance of different artistic groups in a single competition that takes place over several days, without considering any other events.

3 MATHEMATICAL MODEL

The competition of the Carnival of Promises is organized in two rounds of ten stages (one stage per day). Each stage is composed by four time slots, each one of them devoted to the performance of one of the artistic groups. Each artistic group participates in only one of the following categories: "murgas", "societies of lubolos", "humorists", "parodists” and "magazines". There are certain artistic groups (of different categories) that are selected to open, and to close, each stage. A major challenge we faced for building the mathematical model was how to measure the public attendance in order to define the objective function. The way chosen was through the use of surveys. Thus, one delegate from each artistic group had to indicate whether the expected attendance for the rest of the groups was high, medium or low. The organizers decided that each group should only rate the groups in those categories different from their own, with the aim of achieving greater objectivity and avoiding possible conflicts between the groups.

To formulate a mixed-integer linear programming for the problem (MILP), we consider the following sets: rounds (C), stages (D), time slots (T), artistic groups to be scheduled (A), artistic group categories (M, P, H, L, R), groups with music band (B) and groups that can open ($R2$) and close ($R1$) at any stage. The model has the following discrete decision variables. Binary variable $x_{i,d,t,c}$ is equal to 1 if the artistic group i is assigned to stage d and time slot t in round c; 0 otherwise. Binary variable $s_{k,t,c}$ is equal to 1 if any group of category k is assigned to the time slot t, in round c; 0 otherwise. In addition, the continuous variables w, z_c and $y_{d,c}$ are used to measure the deviation from the expected (average) public attendance.

Due to the length of the mathematical formulation, we do not present it in full, but instead we chose to describe here some of the most representative constraints and the objective function of the model. The complete mathematical model can be found at the following link: https://www.fing.edu.uy/owncloud/index.php/s/Q96nyg7nn3Ef2w8.

The objective function (1) minimizes the sum of the deviations from the average popularity weighing of each round c.

$$\min \sum_{c \in C} z_c \qquad (1)$$

Equations (2) determine the popularity weighing at each stage d of round c, where V_i indicates the public attendance value of each group i.

$$y_{d,c} = \frac{\sum_{t \in T} \sum_{i \in A} V_i x_{i,d,t,c}}{|T|} \qquad d \in D, c \in C \qquad (2)$$

Constraints (3), (4) and (5) determine, for each round c, the deviation from the average public attendance value w; these deviations are used in the objective function.

$$w = \frac{\sum_{i \in A} V_i}{|A|} \tag{3}$$

$$z_c \geqslant y_{d,c} - w \qquad \forall c \in C, d \in D \tag{4}$$

$$z_c \geqslant w - y_{d,c} \qquad \forall c \in C, d \in D \tag{5}$$

Constraints (6) establish that the groups with music band (set B) can be assigned at most once for any stage d and round c. This decision is based on the the amount of time required to prepare the performance of these artistic groups, which makes it inconvenient to have two different music bands performing at the same stage.

$$\sum_{t \in T} \sum_{i \in B} x_{i,d,t,c} \leqslant 1 \qquad d \in D, c \in C \tag{6}$$

There are also other constraints to establish that each artistic group must be assigned only once to a time slot and stage, for each one of the rounds.

Constraints (7) and (8) define the groups that can open or close the stages in both rounds.

$$x_{i,d,|T|,c} = 0 \qquad \forall c \in C, d \in D, i \in A \setminus \{R1\} \tag{7}$$

$$x_{i,d,1,c} = 0 \qquad \forall c \in C, d \in D, i \in A \setminus \{R2\} \tag{8}$$

Equations (9) ensure that no pairs of groups assigned to the same stage in the first round, are assigned to the same stage in the second round.

$$\sum_{t \in T} x_{i,d,t,1} + \sum_{t \in T} x_{p,d,t,1} + \sum_{t \in T} x_{i,\ell,t,2} + \sum_{t \in T} x_{p,\ell,t,2} \leqslant 3, \qquad \forall d, \ell \in D, \forall i \in A, \forall p \in A \setminus \{i\} \tag{9}$$

There is a set of constraints to ensure the alternation of group categories in the last time slot of consecutive stages, as defined by Equations (10) for the category of groups P.

$$\sum_{i \in P} x_{i,d,|T|,c} + \sum_{i \in P} x_{i,d+1,|T|,c} = 1 \qquad \forall d \in [1, |D| - 1], \forall c \in C \tag{10}$$

We want to highlight the set of constraints such as (11), to establish a time window of two days for the second round stage of each group considering the first round stage assigned to it. The allowed alternatives are shown in Fig. 2, where the number in each cell represents the stage of the first round. We define the set DL={3,5,6,8} including those stages for which the difference between the two rounds is less than two days.

$$\sum_{t \in T} x_{i,d,t,1} \leqslant \sum_{d' \in [(d-2),(d+2)]} \sum_{t \in T} x_{i,d',t,2} \qquad d \in DL, \forall i \in A \tag{11}$$

There is a set of constraints to establish an order in the participation of the different categories, as defined by the organizers of the competition. For example, Equations (12) establish that the groups of categories 1 and 2 ("murgas" and "societies of lubolos", respectively) must be assigned to the same time slot at each round. Then, constraints (13) impose that all the groups of the category "societies of lubolos" must be assigned to the same time slot.

ROUND 2

1	2	3	4	5	6	7	8	9	10
1	1	1	1	3	4	5	6	7	7
2	2	2	2	4	5	6	7	8	8
3	3	3	3	5	6	7	8	9	9
4	4	4	4	6	7	8	9	10	10
		5	5	7	8	9	10		
			6			10			

Figure 2: Day spacing scheme between rounds for groups.

$$\sum_{t \in T} s_{k,t,c} = 1 \qquad k \in (1, 2), \forall c \in C \tag{12}$$

$$\sum_{i \in L} \sum_{d \in D} x_{i,d,t,c} \geqslant |L|.s_{2,t,c} \qquad c \in C, \forall t \in T \tag{13}$$

Finally, there are some constraints to establish the latest or earliest time slot at which the groups of a given category must carry out their performance in each round, such as those shown in (14) and (15). Numbers HN and HU indicate the maximum and minimum of artistic groups of category "humorists" that must act on the second and third time slot, respectively, at each round c of the contest.

$$\sum_{i \in H} \sum_{d \in D} x_{i,d,2,c} \leqslant HN \qquad c \in C \tag{14}$$

$$\sum_{i \in H} \sum_{d \in D} x_{i,d,3,c} \geqslant HU \qquad c \in C \tag{15}$$

We note that when considering 40 groups and 5 categories, as is usual in practice, 2 rounds with 10 stages and 4 time slots for each on of them, the model developed has over 3,200 binary variables and over 150,000 constraints.

4 RESULTS AND ANALYSIS

We used AMPL and CPLEX optimization solver version 12.9.0.0 to encode and solve the model, respectively. For the executions we employed a PC Intel Core i7 CPU-3.40GHz -24GB RAM.

In the 2019/2020 edition of the Carnival of Promises contest, 6 "murgas", 3 "societies of lubolos", 11 "humorists", 12 "parodists" and 8 "magazines" competed for the first place at each category. The number of groups that could open a stage was 20 and the number of groups that could close a stage was 10. The average of the public attendance after processing the surveys was $w = 5.51$, considering the values $V_i = 1$, $V_i = 5$ and $V_i = 10$ for low, medium, and high attendance of the artistic group i, respectively.

Fig. 3 shows the evolution of the objective value and the duality gap when solving the model with the values of the parameters described above. We observed that an execution time of 2,300 seconds was necessary to obtain a first feasible solution. Then, the objective value decreased to 78% and the duality gap to 1.7% in the next 7,500 seconds. During the remaining running time, 4400 seconds, there were no variations. The final results (after more than 4hs of execution) were: objective value equal to 2.17

(round 1 with 0.84; round 2 with 1.33) and duality gap of 97.79%. We define the final solution obtained as the base solution.

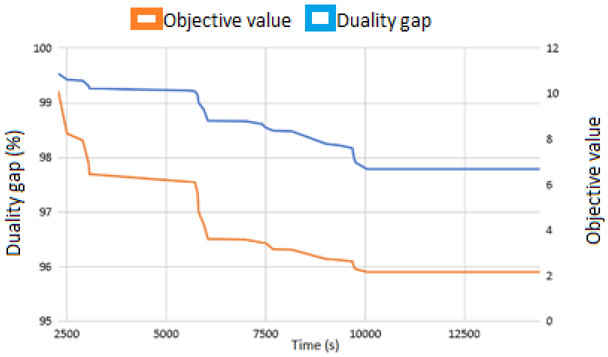

Figure 3: Duality gap and objective value evolution.

The fixture that results from the base solution (Fig. 4) was presented in a public event where all the participants in the different groups and local authorities attended, with a very high satisfaction level from all the stakeholders involved in the competition. Fig. 4 provides the average attendance obtained for each stage 1 to 10, in the last row of the table for the rounds 1 and 2. The cells represent the time slots assigned to "magazines" in red, "parodists" in yellow, "humorists" in blue, "murgas" in green and "societies of lubolos" in purple, respectively.

Round 1

	1	2	3	4	5	6	7	8	9	10
1	LOS BUSCADORES	ZABRITOS	CELESTINOS	JADE	SIDNEY	LOS CHAPITAS	MANDALA	INDIGOS	TROYANOS	TOON'S
2	WONKAS	LA DESCOCADA	OHANA	CROSSED	DIABLITOS VERDES	PRINCIPES	SUENA LA MADERA	CHIN PUM FUERA	TOCANDO LUNAS	LOS PEPINITOS
3	CACHIRULOS	BAM BAM	VALU'S	GNOMOS	ZODIACO	LOS VAGABUNDOS	ALIADOS	ATOMIX	GREMLINS	LOS TOBY'S
4	LA ZAFADA	DULCINEA	POPPIN'S	MANO A MANO	BUBY'S BIS	FENIX	QUIJOTES	ADRENALINA	IMAGINE	SAPHIRUS
Average	5,48	5,52	5,59	5,49	5,62	5,69	5,30	5,35	5,57	5,55

Round 2

	1	2	3	4	5	6	7	8	9	10
1	OHANA	WONKAS	DIABLITOS VERDES	LA DESCOCADA	SUENA LA MADERA	PRINCIPES	LOS PEPINITOS	TOCANDO LUNAS	LOS TOBY'S	CHIN PUM FUERA
2	ZABRITOS	JADE	CELESTINOS	LOS BUSCADORES	CROSSED	ZODIACO	MANDALA	TOON'S	INDIGOS	TROYANOS
3	GNOMOS	BAM BAM	CACHIRULOS	LOS CHAPITAS	VALU'S	ATOMIX	SIDNEY	LOS VAGABUNDOS	GREMLINS	ALIADOS
4	LA ZAFADA	POPPIN'S	DULCINEA	BUBY'S BIS	FENIX	MANO A MANO	IMAGINE	ADRENALINA	QUIJOTES	SAPHIRUS
Average	5,71	5,18	5,32	5,20	5,79	5,71	5,22	5,81	5,73	5,47

Figure 4: Fixture of the base solution.

Considering the computational effort required to obtain a feasible solution to the suggested MILP, an alternative way of solving the problem was developed and evaluated. The alternative involves sequentially solving two models, one for each round of the fixture. In the first model, the variables and constraints related to round 2 in the original MILP are deleted, and a schedule is obtained only for round 1 of the competition. For the round 2 model, the values of the variables corresponding to round 1 in the original MILP are entered as parameters, in order to obtain a round 2 that considers the round 1 schedule.

We observe that solving sequentially the models of round 1 and 2, requires much less processing time than for the complete model of both rounds (seconds versus hours). Indeed, for the first model we obtain a solution in 2.2 seconds with an optimal value of 0.06 for round 1. To analyze the difference with the round 1 of the base solution, we use a Hamming distance approach, which results in 35 different assignments of groups in the total of 40 groups. Therefore, round 1 of both fixtures differ substantially. In fact, the objective value of the optimal solution of the round 1 model is much better than that of round 1 of the base solution

Table 1: Results of the numerical experimentation with stage suspensions in round 1.

Case	Number of suspended stages	Round 2 objective value	Hamming distance
base sol.	0	0.84	0
A	1	3.24	31
B	2	4.02	24
C	2	4.04	31
D	3	3.85	37
E	3	6.71	37

(0.06 versus 0.84). This is not surprising since the model from round 1 is less restrictive than the original model from both rounds. However, for the round 2 model we observed that there was no feasible solution, i.e., there is no fixture for round 2 that satisfies all the imposed restrictions and the given round 1 fixture. Therefore, we conclude that the alternative of the two models, one for each round, is not always applicable to obtain a complete schedule. This will depend largely on the data of the instance.

Despite the undesirable effect mentioned above, the solving alternative of two models can be useful in practice, in the cases described as follows. The competition takes place in an open-air theater, which implies that in the event of inclement weather, such as heavy rains or winds, the performance of one or more stages must be suspended. The suspended stages are postponed until after the last stage of the established fixture, respecting the same order and schedule. In addition, if round 1 is rescheduled due to the suspension of any of the stages of the initial fixture, round 2 must also be rescheduled since changes made to the schedule of round 1 can affect the schedule of round 2. Thus, in order to obtain the schedule for round 2 only, we can use the round 2 model of the proposed solving alternative of two models. We also note that a resolution time of a few seconds for the round 2 model is very important in practice, because the time distance between rounds 1 and 2 is very few days. Therefore, the new round 2 schedule should be available as soon as possible, so that the groups can properly prepare their second performance. In the case of no feasible solution existing for the round 2 model, we consider the following two alternatives: maintain the original schedule for round 2 obtained by solving the original two-round model which is a good quality schedule, albeit due to the changes in round 1 will not comply all constraints; or relax some of the constraints of the round 2 model, after coordinating with the organizers of the contest.

Table 1 summarizes the results obtained from the experiments carried out to evaluate the effect on rescheduling round 2 by suspending different stages at round 1. The stages suspended for each case in the table are as follows: A, stage 4; B, stages 2 and 6; C, stages 7 and 8; D, stages 3, 5 and 6; E, stages 1, 2 and 5. First, it is observed that for all cases, the objective value of the optimal solution of the round 2 model is significantly worse than that of round 2 of the base solution. This can be explained by the fact that the round 2 model is more restrictive than the original two round model. Second, there is no obvious relationship between the number of suspended stages in round 1 and the number of changes in the new schedule obtained for round 2, as indicated by the Hamming distance column of Table 1. Therefore, we can conclude that even minor changes to the round 1 schedule can have a large impact on the round 2 schedule.

5 CONCLUSIONS

This paper presents an application of quantitative methods to the problem of obtaining the schedule of the Carnival of Promises competition from Uruguay. This is a relevant cultural event in the country, involving a large number of children and teenagers. In the past, the fixture has always been created manually by the competition organizers. This task involved many days of work and usually the final fixture did not satisfy all the parties involved, in particular the different artistic groups. Here, a mixed integer linear programming model for this problem is proposed and evaluated. In addition to considering the constraints imposed by the competition regulations and others indicated by the organizers, it was necessary to develop a method for estimating public attendance to define the objective function. We highlight that the model was used in practice to obtain the fixture of the 2019/2020 competition [8].

Considering the computational time required for solving the proposed model, an alternative consisting in solving two sequential models (round 1 and round 2) was explored. Although this alternative significantly reduces the computational time required, it cannot guarantee a feasible solution for the round 2 model. This will depend on the data of each instance. However, the two model approach can be very useful in practice. Due to unforeseen changes in round 1, round 2 often has to be rescheduled. This new round 2 schedule should be determined as quickly as possible and after round 1 is finished. In the cases when there is no feasible solution for the round 2 model, one or more constraints should be relaxed, in agreement with the competition organizers.

Having worked on this problem has been a very enriching experience. On the one hand, it allowed us to apply an Operations Research approach to a problem in the field of culture, which we consider to be very innovative. It also allowed us to contact many young people, who can see in this experience a possibility of applying science and engineering to a daily situation for them and in this way motivate them to continue their studies in these disciplines. In addition, for the competition organizers, this work showed them a more effective way to make the fixture and have objective support for their decisions beyond their experience.

It would be possible to change the objective function in order to maximize audience participation. This would imply working in conjunction with other areas such as marketing or communications. In order to closer model reality, the different hours and days could be weighted to take into account audience preferences. Otherwise, other ways of measuring attendance could also be evaluated. In addition, the model could be adapted and generalized to be employed in other contests with similar characteristics.

Future work should include an in-depth study of the model to determine if it is possible to reduce the resolution times. For instance, it would be interesting to find a way to reduce the number of discrete variables, as well as incorporating additional constraints to eliminate symmetries (feasible solutions with the same objective value). Given that the models of round 1 and round 2 require much less resolution time than the original model of two rounds together, an interesting option to investigate is to generate many solutions of round 1 and feeding the model of round 2 with each of these solutions, thus increasing the possibility of finding a feasible solution for round 2. Another direction of future research is to develop approximate solving procedures for the problem, such as constructive heuristics or those based on metaheuristics. Even, the model could be initialized with the solution obtained by using these procedures. In this regard, we have already carried out tests feeding the model with partial initial solutions, without obtaining substantial improvements in the resolution times [5]. Lastly, proactive and reactive approaches similar to those proposed in [16] could be explored to address the problem of rescheduling due to unforeseen events.

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