A Multi-objective Model for Publicly Funded Festival Planning

L. Alçada-Almeida[12], *N. Sousa*[13], *J. Coutinho-Rodrigues*[14*]

[1]Researcher, INESC-Coimbra, Portugal
[2]Assistant Professor, Faculty of Economics, University of Coimbra, Portugal
http://orcid.org/0000-0003-1272-9053
[3]Assistant Professor, Department of Sciences and Technology, Universidade Aberta, Lisbon, Portugal
https://orcid.org/0000-0002-2681-5035
[4]Full Professor, Department of Civil Engineering, Faculty of Sciences and Technology, University of Coimbra, Portugal
https://orcid.org/0000-0001-9311-5584
[*]Corresponding author: coutinho@dec.uc.pt

Abstract

This article proposes a multi-objective mixed-integer linear programming model to assist event managers in obtaining and evaluating non-dominated solutions to the problem of selecting a daily lineup of shows and activities for a festival – be it cultural, sports, ceremonial, or any other kind. The model, which is especially adequate for designing festivals with public funding, has five objectives, relating to financial, logistical, and how renowned the festival artists or acts are. It includes support for multiple days, multiple stages, and different types of shows, all subject to constraints imposed by the intrinsic nature of the festival itself. The output of the model is a set of optimized daily lineups for the activities that constitute the festival, each corresponding to a particular compromise between the five objectives. The approach is demonstrated with a case study for a 5-day festival, for which non-dominated solutions are derived, presented, and discussed. Results show that the model can provide a good variety of solutions while ensuring persistence of the more desirable shows. The model is a novel decision support tool to assist in designing festival lineups which provide optimal audience experience, a key factor in attracting spectators, tourists, and increasing comeback value.

Keywords: event and festival planning, multi-objective optimization, mixed-integer linear programming, cultural event management.

1. Introduction

Ever since the creation of societies, people have organized large-scale events of various types, be it cultural, sports, ceremonial, or any other kind (Maeng et al., 2016). Henceforth designated as 'festivals', these events celebrate cultural heritage, societal aspects, and contribute decisively towards defining a society's collective identity (Ferdinand and Williams, 2013; Tanford and Jung, 2017). Festivals play an important role in fostering tourism (Lin and Chang, 2020) and are very often considered in the marketing of destinations (Chang, 2006; Getz, 2008; Picard and Robinson, 2006), increasingly calling out to both national and international audiences. Festivals fall into the category of event tourism (Getz, 2008), which involves the travelling of people to attend the events, benefiting hosting communities at the economic, social, cultural, and well-being levels (Arcodia and Whitford, 2006; Grappi and Montanari, 2011; Yolal et al., 2016).

Given the rising numbers in festival attendance worldwide and growth projections prior to the COVID-19 pandemic (see e.g., Weber and Hsu, 2021), which could reach hundreds of thousand visitors (Honggen and Smith, 2003; Richter, 2019), an optimized management of these events is likely to produce sizeable plus-values to both attendees and the hosting community. Recent research puts festival tourism as one of the fastest-growing fields in the industry and examples exist where high competition between local events and low program quality led to low tourist satisfaction (Choi et al., 2021; Weber and Hsu, 2021; van Heerden and Saayman, 2018). This highlights the need for decision support tools for festival planning, first and foremost *per se*, but also because rising attendance is likely in the aftermath of COVID-19 (Miao et al., 2021; PwC, 2021; Zhong et al., 2021). The high costs associated to the production and programming of festivals, the ever-easier access to global information about artistic production (contacts, costs, agendas, etc.), and the existence of mutually conflicting objectives and restrictions when attempting to design concrete daily lineups, make it evident that it is not possible for a human to process the full complexity of the information involved, while retaining the efficiency and effectiveness levels that the festival's relevance requires. Despite this, few theoretical studies exist on the management and organization of festivals, as recognized by Getz (2008). To give festival management the predominant role it calls for, it is thus necessary to develop decision support tools which can aid organizers to find the best lineup of shows, taking into consideration the multiple dimensions of reality such events deal with.

Literature themes on event studies have been summarized by Patterson and Getz (2013) and, in what respects tourism festivals, Yan et al. (2017) identified the following three major categories of Patterson and Getz as especially relevant: event planning and management from the supply side, antecedents to participation/attendance (the demand side), and the measured outcomes. The research presented herein falls on the event planning and management line of research and is motivated both by the need to develop the aforementioned decision support tools and because it addresses the important issue of quality of program, a topic identified by Saleh and Ryan (1993), Kinnunen and Haahti (2015), and Tan et al. (2020) as an important factor attracting tourists to festivals. It also increases quality experience, a driver of comeback value (Gannon et al., 2019), particularly for tourists of the hedonist kind (Serrato et al., 2010). Quality of program deals essentially with determining the lineup of shows, within the constraints imposed on the organization.

In order to address the problem of finding optimized daily lineups for festivals, this article proposes a multi-objective mixed-integer linear programming model, which can assist festival organizers and managers in selecting the best possible lineup of shows or, more broadly, activities. The model considers five objectives, namely: (*i*) minimization of costs and (*ii*) logistic complexity, and maximization of (*iii*) how renowned artists are, (*iv*) stage occupation, and (*v*) correspondence between audience expectations and seats offered. Sets of constraints which represent specific aspects of a festival are also supported. It is a decision support tool for event planning, generating options and solutions that optimize the satisfaction provided to the audience to a grand event and is, to best of the authors' knowledge, one of the first attempts of addressing the festival planning problem with exactly solvable mathematical models. Because the model focuses on cost minimization, rather than generation of profit, it is especially adequate for organizations that typically seek lower costs or deal with limited budgets, such as e.g., public entities or public-private partnerships.

2. Literature review

Since this article relates to both festivals and event planning and management, the literature review focuses on festivals and other events that may require similar approaches. Event planning and management is one of the cornerstones of the *framework for studying knowledge on event tourism* proposed by Getz and Page (2016) and studies on the subject have mostly focused on issues of development and marketing (Bramwell, 1997; Getz, 2016; Gursoy and Kendall, 2006; Mackellar and Nisbet, 2017; Pappas, 2014; Phi et al., 2014; Tkaczynski, 2014; Weed and Bull, 2009), strategy (Baumann et al., 2009; Ford et al., 2009; Stokes, 2006, 2008), and image and branding (Arellano, 2011; Chalip and Leyns, 2002; Chalip and McGuirty, 2004; Hede, 2005; Jago et al., 2003; Karadakis et al., 2010; Kim et al., 2014; Li and Vogelsong, 2005; O'Brien, 2006; Ritchie, 2000; Smith, 2005; Ziakas and Getz, 2021). However, all the above are top level approaches, in the sense that researchers try and understand how to best explore synergies between stakeholders, local communities and media broadcast, with the objective of maximizing visitor experience, economic impact, and comeback value. The approaches concentrate on strategic aspects and do not go down to the level of selecting the individual activities that form the festival. The general literature in planning and scheduling of multiple activities is rich, but concentrates on subjects that are very different from festivals. Typical examples are personnel scheduling problems, in which an optimal scheduling of employees and jobs is sought-after (Özder et al., 2020; Van den Bergh et al., 2013), including variations such as multi-skilling (Afshar-Nadjafi, 2021), multi-skilling with partial preemption (Polo Mejía et al., 2023); project scheduling problems, which deal with optimizing the scheduling of a complete set of jobs under specific conditions (Fotedar et al., 2023; Schwindt and Zimmermann, 2015), with variations such as time-dependent scheduling (Gawiejnowicz, 2020) or the resource-constrained project scheduling (Hartmann and Briskorn, 2010; Coelho and Vanhoucke, 2011); and machine scheduling problems, where a set of jobs is to be processed by assembly machines (Abedinnia et al., 2017; Zhang et al., 2023). Sports planning and scheduling is closer to the topic of this article but, as the review of Ribeiro (2013) showed, most problems tackled in the literature deal with very specific issues such as e.g., minimizing team distance travelled (Ribeiro and Urrutia, 2007) (see Kendall et al. [2010] for more examples), rather than broader issues such as Olympiad planning, a problem akin to the one this research targets. Albeit these examples address a very broad array of problems, none of them deals with all the specifics of festival planning. The model herein proposed does not require, for instance, every artist under consideration to be hired and assigned to a stage at a given day. Consequently, the set of activities to be lined up is not fixed but decided by the model *a posteriori*. Also, model objectives related to audience expectations and artist (or act) renown, as well as the set of constraints, are unique to festivals. To best of authors knowledge, no example exists in the literature which focuses specifically on planning festival lineups using mathematical optimization techniques. The present research makes a contribution towards filling this literature gap, bringing mathematical programming to the field of festival management, a technique that has been successfully utilized in other fields of tourism management, such as e.g., the generation of optimized tour routes (Zheng and Liao, 2019; Zheng et al., 2020), shuttle vehicle scheduling (Liu et al., 2023) and routing (Hu et al., 2023), the exploration of sustainable ecotourism solutions (Zografos and Oglethorpe, 2004), or the modelling of multi-period tourist car trips (Taplin and McGinley, 2000).

3. The Model

In this article a 'festival' is defined as a series of individual events, or activities, taking place in different locations, within time windows which can span multiple days, such that different activities cannot overlap in location. To simplify the approach and rigorously identify valid and widely representative objectives, the option was taken to base the model on the planning of a festival in the specific field of arts and culture. Concretely, this could mean an arts festival, event planning for a city of cultural capital status, etc. Without any loss of generality, the model is extendable to festivals of different natures and themes, as long as the overall structure is consistent with the model premises. The model is a planning tool intended to assist festival organizers, which play the role of the decision maker, to select the shows (i.e., acts, or activities) that will make up the festival, and their respective daily lineup, in a way which respects all the constraints imposed by the festival's context. It operates mainly at the strategic level, by helping in selecting the activities, but incorporates operational considerations that see to the feasibility of those selections. The model provides daily lineups for the festival, but leaves the decision maker free to schedule, i.e., time-order them within each day.

Determining the contents and lineup of an arts and culture festival can be seen in the perspective of offering an entertainment product (or service) which, in its final form, will be perceived by the public as more than just a compilation of a set of experiences that could be acquired separately (Allen et al., 2010). From the point of view of a festival, hiring and lining up individual activities can be considered as event programming. In addition, one must add-up all actions of diverse nature that integrate the global experience – venue preparation, concessions, licenses, conceptualization of the environment, risk management, attendance of guests and artists, budgeting, etc.

The model proposed is a mixed-integer linear programming (MILP) model, with five objectives addressing different dimensions of the decision-making process: the first objective minimizes cost, a ubiquitous goal in management problems. The second and third objectives maximize, respectively, the correspondence between the categories of activities and the expectations of the public (in terms of places offered), and how renowned the artists are. Achieving these two objectives provides audiences with quality experiences, fostering their comeback for future events, and provides adequate supply for spectators. The fourth objective minimizes the logistic complexity, thus decreasing the probability of unforeseen delays and improving timekeeping of the event, which is also important for a quality experience. The fifth objective maximizes daily occupation of stages, making sure resources available are used as much as possible. These objectives were normatively set, based on the experience of the research team members, one of which has worked on the field of publicly funded festivals, and on information available in the literature, which signaled them as important in event and cultural management (Boatwright et al., 2007; Papies et al., 2017; Taneja and Bala, 2022; Wee et al., 2012). Note that part of the normative nature of the model appears because, to best of the authors' knowledge, no explicit formulation exists in the literature for concepts such as correspondence of expectations, renown, or logistic complexity, so these had to be modelled in mathematical terms for the context of this research, from the authors' experience.

Another important point to note is that a multi-objective approach is justified because, as mentioned, planning and organizing a festival naturally encompasses multiple dimensions of reality. Private organizers often simplify this complexity by considering the different dimensions in a purely financial manner, so that a profit maximization approach can be subsequently followed. Public organizers have a different strategic managerial objective, which is to provide the most effective service possible to the population (a quality festival) in the most efficient way possible (cheapest, less complex, fullest use of resources). So, they need to consider several aspects, not just the one-dimensional 'cost vs. revenue' conundrum that is more characteristic of private organizers. Thus, because the proposed model considers multiple dimensions independently, it is naturally more suited to plan publicly funded festivals. Or, seeing it the other way around, if a decision aid model for publicly funded festivals is sought, then it should consider different dimensions of reality, and this justifies the multi-objective approach that is followed herein.

In the context of an arts and culture festival, the parameters, indexes, and decision variables describing it were identified and are presented in Tables 1-3 below. The multi-objective model is then presented, together with a motivation for its set of constraints. Also, superscripts are to be read as indexes, not exponents.

Table 1. Model parameters.

Parameter	**Type**	**Description**	**Observations**
N^D	Integer	Nr. of festival days	
N^H	Integer	Nr. of activity areas	For $N^H = 3$ these areas could be e.g., 1. Music, 2. Dance, 3. Theatre. An area may contain different categories, e.g., Music: rock, classical, electronic; Dance: ballet, contemporary; Theatre: drama, comedy.
N^C	Integer	Nr. of categories	Total number, the sum of all categories for each area. For the example above, $N^C = 7$.
N_c^A	Integer	Nr. of activities of category *c*	Not all activities need to be lined up.
N^S	Integer	Nr. of available stages	Stage is taken in a broad sense, e.g., street location, exhibition site, etc.
N_s^P	Integer	Nr. of places for spectators of stage *s*	Places can be either seats or spaces for standing spectators.

N_c^{mC}	Integer	Minimum nr. of activities of category *c* to line up	Occurrences in the solution. E.g., if $N_c^A = 4$ and $N_c^{mC} = 3$, at least three activities of category *c* must feature in the solution.
N_c^{MC}	Integer	Maximum nr. of activities of category *c* to line up	
N_{ac}^{mA}	Integer	Minimum nr. of occurrences of activity *a* of category *c*	The same activity may be repeated in different days ($N_{ac}^{mA} > 1$).
N_{ac}^{MA}	Integer	Maximum nr. of occurrences of activity *a* of category *c*	
N_{ac}^{MBA}	Integer	Maximum nr. of blocks of occurrences of activity *a* of category *c*	Example: in a one-week festival, if the same activity *a* occurs in days 1-3 and 5-7, there are two blocks. If it occurs in days 1-2, 4-5, and 7, there are three blocks.
C^M	Real	Maximum festival budget	
C_{ac}^A	Real	Cost of activity *a* of category *c*	
C_c^{MC}	Real	Maximum budget for category *c*	Alternatively, one could opt for a per-area budgeting (see comments to constraints 11).
W_c^C	[0,1]	Importance (weight) given by the public to category *c*	$\sum_c W_c^C = 1$. Weights are attributed by the decision maker, based on his experience, previous attendances, or media impact.
W_{ac}^A	[0,1]	Importance given by specialized critics to activity *a*, within category *c*	$\sum_{a=1}^{N_c^A} W_{ac}^A = 1$. Attributed by the decision maker, based on his experience or critics' scores (e.g., movie ratings, etc.).
W_{ac}^{LA}	[0,1]	Logistical complexity of activity *a*, within category *c*	Complexity refers to stage preparation and operation; 1 = very complex activity, 0 = not complex. Attributed by the decision maker, based on his experience and proficiency of support teams.
D_{ac}^A	Real	Duration, in hours, of activity *a* of category *c*	Includes preparation and clean-up of the stage.
S_{ac}^{FA}	Integer	Label of stage pre-assigned to activity *a* of category *c*	If $S_{ac}^{FA} = 0$, activity *a* can be lined up for any compatible stage. Else, if activity *a* is lined up, it must be to a stage with label S_{ac}^{FA}.
D_{sd}^S	Real	Availability, in hours, of stage *s* in day *d*	
A_{sc}^S	Binary	1 if stage *s* is suitable for activities of category *c*, else 0	
H_c^C	Integer	Code of the area of category *c*	Relates areas and categories.
H_{ac}^*	Binary	1 if activity *a* is the star activity in its area, else 0	Example: for the music area, 1 for the lead band, 0 for support bands. Maximum 1 star activity lined up per area, per day.

Table 2. Model indexes

Index set	Index name	Description	Range
H	h	Area	$1,\ldots,N^H$
C	c	Category	$1,\ldots,N^C$
A^C	a	Activities of category c	$1,\ldots,N^A_c$
S	s	Stage	$1,\ldots,N^S$
D	d	Day	$1,\ldots,N^D$

Table 3. Model decision variables

Variable	Type	Description	Observations
x_{acsd}	Binary	1 if activity a of category c is lined up to stage s on day d, else 0	Variable count: $N^S N^D \sum_c N^A_c$.
z_{acd}	Binary	1 if activity a of category c is lined up to day d, else 0	Variable count: $N^D \sum_c N^A_c$.
y_{acd}	Binary	1 if activity a of category c is lined up to day d, but not to the day before, else 0	Variable count: $N^D \sum_c N^A_c$.

Unless otherwise stated, summations run over the extent of the index set. In particular, note that activities always have an associated category, so summations over a run from 1 to N^A_c.

The multi-objective mathematical model is formulated as follows.

Objectives:

O1: minimization of the total cost of the festival.

$$\min O_1 = \sum_d \sum_s \sum_c \sum_a C^A_{ac} x_{acsd} \tag{1}$$

The right-hand-side represents total cost, i.e., the sum of all C^A_{ac} that are lined up. The setup of objectives is geared towards minimizing costs while providing the best service possible to the audiences. The model is thus especially adequate for management structures that deal with limited budgets as, e.g., events with public funding or public-private partnerships, who may be more worried of adhering to budgets than considering profits *a priori* in the modelling approach. It may also be used as the planning method of choice if pricing is to be considered *a posteriori*.

O2: maximization of the correspondence, in terms of places on offer, between the categories of activities and the expectations of the public.

$$\max O_2 = \sum_d \sum_s \sum_c \sum_a W^C_c W^A_{ac} N^P_s x_{acsd} \tag{2}$$

How renowned an artist may be is defined as the product of the importance given by the public to its category (W_c^C) and importance given by specialized critics within that category (W_{ac}^A). Multiplication of how renowned the artist may be by stage places (N_s^P) yields the correspondence between the availability of places and audience expectations. This objective suggests placing the more renowned artists in larger stages.

O3: maximization of how renowned the artists are.

$$\max O_3 = \sum_d \sum_s \sum_c \sum_a W_c^C W_{ac}^A x_{acsd} \qquad (3)$$

This objective is similar to O2 and suggests contracting the more renowned artists, which have higher values for the $W_c^C W_{ac}^A$ product.

O4: minimization of logistic complexity.

$$\min O_4 = \sum_d \sum_s \sum_c \sum_a W_{ac}^{LA} x_{acsd} \qquad (4)$$

More complex activities have higher W_{ac}^{LA}, which may cause unforeseen delays and disrupt festival flow. In the context of an arts festival, logistic complexity is usually associated with more renowned artists. This need not be so for other types of festivals (e.g., sports), so this objective may, or may not, align with O2 and O3.

O5: maximization of daily occupation of stages.

$$\max O_5 = \sum_d \sum_s \sum_c \sum_a D_{ac}^A x_{acsd} \qquad (5)$$

This objective tends to favor activities with longer duration, i.e., higher D_{ac}^A. Occupancy does not discriminate between stages.

Constraints:

$$\sum_s x_{acsd} = z_{acd} \qquad \forall_a \in A^C,\ \forall_c \in C,\ \forall_d \in D \qquad (6)$$

Each activity is lined up, at most, one time per each day of the event. Recall z_{acd} is binary, so $z_{acd} \leq 1$.

$$y_{ac1} \leq z_{ac1} \qquad \forall_a \in A^C,\ \forall_c \in C \tag{7a}$$

$$y_{acd} \geq z_{acd} - z_{ac(d-1)} \qquad \forall_a \in A^C,\ \forall_c \in C,\ \forall_d \in D{:}d \neq 1 \tag{7b}$$

$$\sum_d y_{acd} \leq N_{ac}^{MBA} \qquad \forall_a \in A^C,\ \forall_c \in C \tag{7c}$$

These constraints impose a maximum number of blocks for each activity, namely N_{ac}^{MBA}. Since idle days exist between blocks, this prevents artists who act more than one time from having too many idle days.

$$x_{acsd} \leq A_{cs}^S \qquad \forall_{a,c} \in \{A^C,C\} : S_{ac}^{FA} = 0, \forall_s \in S, \quad \forall_d \in D \tag{8a}$$

$$x_{acsd} = 0 \qquad \forall_{a,c} \in \{A^C,C\} : S_{ac}^{FA} > 0, \forall_s {:} s \neq S_{ac}^{FA}, \forall_d \in D \tag{8b}$$

Activities can only be lined up for a preset stage or for a stage suitable for its category.

$$\sum_d \sum_s x_{acsd} \geq N_{ac}^{mA} \qquad \forall_a \in A^C,\ \forall_c \in C \tag{9a}$$

$$\sum_d \sum_s x_{acsd} \leq N_{ac}^{MA} \qquad \forall_a \in A^C,\ \forall_c \in C \tag{9b}$$

Each activity is lined up a number of days between preset minimum (N_{ac}^{mA}) and maximum values (N_{ac}^{MA}). These constraints may be used e.g., to ensure that a famous artist whose audience could overbook the venue on one day is repeated at least a certain number of days, giving everybody a chance to watch it.

$$\sum_c \sum_a D_{ac}^A x_{acsd} \leq D_{sd}^S \qquad \forall_d \in D,\ \forall_s \in S \tag{10}$$

For each day D, the activities lined up to stage S cannot exceed its time availability, D_{sd}^S. This constraint prohibits stage overbooking.

$$\sum_d \sum_s \sum_a C_{ac}^A x_{acsd} \leq C_c^{MC} \qquad \forall_c \in C \tag{11a}$$

$$\sum_d \sum_s \sum_c \sum_a C_{ac}^A x_{acsd} \leq C^M \tag{11b}$$

Total (C^M) and category-specific (C_c^{MC}) budget constraints. Festivals usually must deal with budget constraints, regardless of funding source (see e.g., García [2001] for an example from the private sector). Category-specific budgeting is preferred when, within each area, categories are somewhat heterogeneous (e.g., rock and classical music). If area-specific budgets were preferred instead, this constraint would become $\sum_s \sum_{c:H_c^C=h} \sum_a C_{ac}^A x_{acsd} \leq C_h^{MH}$, $\forall_h \in H$, with C_h^{MH} the maximum budget for area h.

$$\sum_d \sum_s \sum_a x_{acsd} \geq N_c^{mC} \qquad \forall_c \in C \qquad (12a)$$

$$\sum_d \sum_s \sum_a x_{acsd} \leq N_c^{MC} \qquad \forall_c \in C \qquad (12b)$$

These constraints impose a minimum (N_c^{mC}) and a maximum (N_c^{MC}) number of activities to line up for each category.

$$\sum_s \sum_{c:H_c^C=h} \sum_a H_{ac}^* x_{acsd} \leq 1 \qquad \forall_h \in H,\ \forall_d \in D \qquad (13)$$

Each area can only have one star activity (H_{ac}^*) per day, e.g., the day a rock star is lined up, no major classical music events may run. Restricting star activities to one per day mitigates audience dispersion within each area. This constraint could, instead, be imposed on a per-category basis, rather than per-area. That would change the constraint to $\sum_s \sum_a C_{ac}^* x_{acsd} \leq 1$, $\forall_c \in C$, $\forall_d \in D$, with C_{ac}^* the star activity in category c.

Other remarks

The model determines which activities should feature in the festival on a daily basis. Since a day is nothing but a period of time, an arbitrary quantity, this period can be altered if the decision maker wishes to have finer-grained time periods, e.g., afternoon/evening split, or even shorter periods. Constraints (7) can be used to make sure activities which span longer than the time period considered are not interrupted.

Model summary

A summarized model formulation is given below.

Model:

$$\min O_1 = \sum_d \sum_s \sum_c \sum_a C_{ac}^A x_{acsd}$$

$$\max O_2 = \sum_d \sum_s \sum_c \sum_a W_c^C W_{ac}^A N_s^P x_{acsd}$$

$$\max O_3 = \sum_d \sum_s \sum_c \sum_a W_c^C W_{ac}^A x_{acsd}$$

$$\min O_4 = \sum_d \sum_s \sum_c \sum_a W_{ac}^{LA} x_{acsd}$$

$$\max O_5 = \sum_d \sum_s \sum_c \sum_a D_{ac}^A x_{acsd}$$

Subject to:

$$\sum_s x_{acsd} = z_{acd} \qquad \forall_a \in A^C,\ \forall_c \in C,\ \forall_d \in D$$

$$y_{ac1} \leq z_{ac1} \qquad \forall_a \in A^C,\ \forall_c \in C$$

$$y_{acd} \geq z_{acd} - z_{ac(d-1)} \qquad \forall_a \in A^C,\ \forall_c \in C,\ \forall_d \in D{:}d \neq 1$$

$$\sum_d y_{acd} \leq N_{ac}^{MBA} \qquad \forall_a \in A^C,\ \forall_c \in C$$

$$x_{acsd} \leq A_{cs}^S \qquad \forall_{a,c} \in \{A^C, C\} : S_{ac}^{FA} = 0, \forall_s \in S, \quad \forall_d \in D$$

$$x_{acsd} = 0 \qquad \forall_{a,c} \in \{A^C, C\} : S_{ac}^{FA} > 0, \forall_s{:}s \neq S_{ac}^{FA}, \forall_d \in D$$

$$\sum_d \sum_s x_{acsd} \geq N_{ac}^{mA} \qquad \forall_a \in A^C,\ \forall_c \in C$$

$$\sum_d \sum_s x_{acsd} \leq N_{ac}^{MA} \qquad \forall_a \in A^C,\ \forall_c \in C$$

$$\sum_c \sum_a D_{ac}^A x_{acsd} \leq D_{sd}^S \qquad \forall_d \in D,\ \forall_s \in S$$

$$\sum_d \sum_s \sum_a C_{ac}^A x_{acsd} \leq C_c^{MC} \qquad \forall_c \in C$$

$$\sum_d \sum_s \sum_c \sum_a C_{ac}^A x_{acsd} \leq C^M$$

$$\sum_d \sum_s \sum_a x_{acsd} \geq N_c^{mC} \qquad \forall_c \in C$$

$$\sum_d \sum_s \sum_a x_{acsd} \leq N_c^{MC} \qquad \forall_c \in C$$

$$\sum_s \sum_{c:H_c^C = h} \sum_a H_{ac}^* x_{acsd} \leq 1 \qquad \forall_h \in H,\ \forall_d \in D$$

Obtaining solutions

In a multi-objective problem, the concept of an optimal solution is replaced with that of an efficient solution, also referred to as non-dominated, non-inferior, or Pareto-optimal solution (Cohon, 1978). These form the Pareto front, i.e., the set of solutions for which no improvement can be found in one objective without degrading values in any other objective (Ehrgott, 2005). A large number of non-dominated solutions usually exist, but it is not realistic to generate the entire set. However, it is important to identify various non-dominated solutions to obtain a general understanding of the underlying trade-offs among the objectives and to help in the search for additional solutions, with an aim at ultimately identifying of the most preferred solution.

Weighted sum method

The search for non-dominated solutions often starts with the weighted sum method. This method allows obtaining individual optima, have a first look at solution space, and derive benchmarks for further exploration of that space. The method works by transforming the original multi-objective problem onto a single-objective problem whose objective function is a convex combination of the original objectives (see e.g., Ehrgott, 2005). The method guarantees the generation of non-dominated solutions and boils down to solving:

$$\max O = \sum_{i=1}^{5} w_i O_i \tag{14}$$

where objectives to minimize are multiplied by -1 and w_i is the weight assigned to objective O_i, normalized such that $\sum_i w_i = 1$.

Since objectives are expressed in different unit scales, it is first necessary to obtain individual optimal solutions, Opt_i, for each of the five objectives by running the model with $w_i \approx 1$ for the sought-after objective and $w_j \approx 0, j \neq i$. The infinitesimal positive value given to w_j ensures the identification of a non-dominated solution. Then, to obtain additional non-dominated solutions, the weights in (14) are replaced at runtime by those given by the calibration formula:

$$\overline{w}_i = w_i \frac{\sum_i \mathrm{Opt}_i}{\mathrm{Opt}_i}, \qquad i = 1,\ldots,5 \tag{15}$$

The Opt_i solutions form the pay-off table and define the *ideal solution*, i.e., $\mathrm{Opt}_i, \forall_i$, which is used as a reference point; a benchmark to guide the search for more solutions.

Once the calibration of (15) is complete, weighted sum solutions can be obtained for any set of w_i. The weighted sum method can be seen as a way to generate non-dominated solutions, whose trade-offs between the different objectives can then be analyzed by the decision maker.

Goal programming

Goal programming is an example of how to use the ideal solution benchmark to derive additional solutions (see e.g., Tamiz and Jones, 1997). Goal programming looks for solutions that minimize distance to a hypothetical solution, which is defined by a set of desired values on each objective (goal). That solution can be, e.g., the ideal, and this is assumed below. Concerning distance, it can be measured by (one of):

$$L_1 = \left|\frac{O_1 - \mathrm{Opt}_1}{\mathrm{Opt}_1}\right| + \cdots + \left|\frac{O_1 - \mathrm{Opt}_5}{\mathrm{Opt}_5}\right| \quad \text{(Manhattan, or linear distance)} \tag{16a}$$

$$L_\infty = \max\left\{\left|\frac{O_1 - \mathrm{Opt}_1}{\mathrm{Opt}_1}\right|, \ldots, \left|\frac{O_1 - \mathrm{Opt}_5}{\mathrm{Opt}_5}\right|\right\} \quad \text{(Tchebyschev distance)} \tag{16b}$$

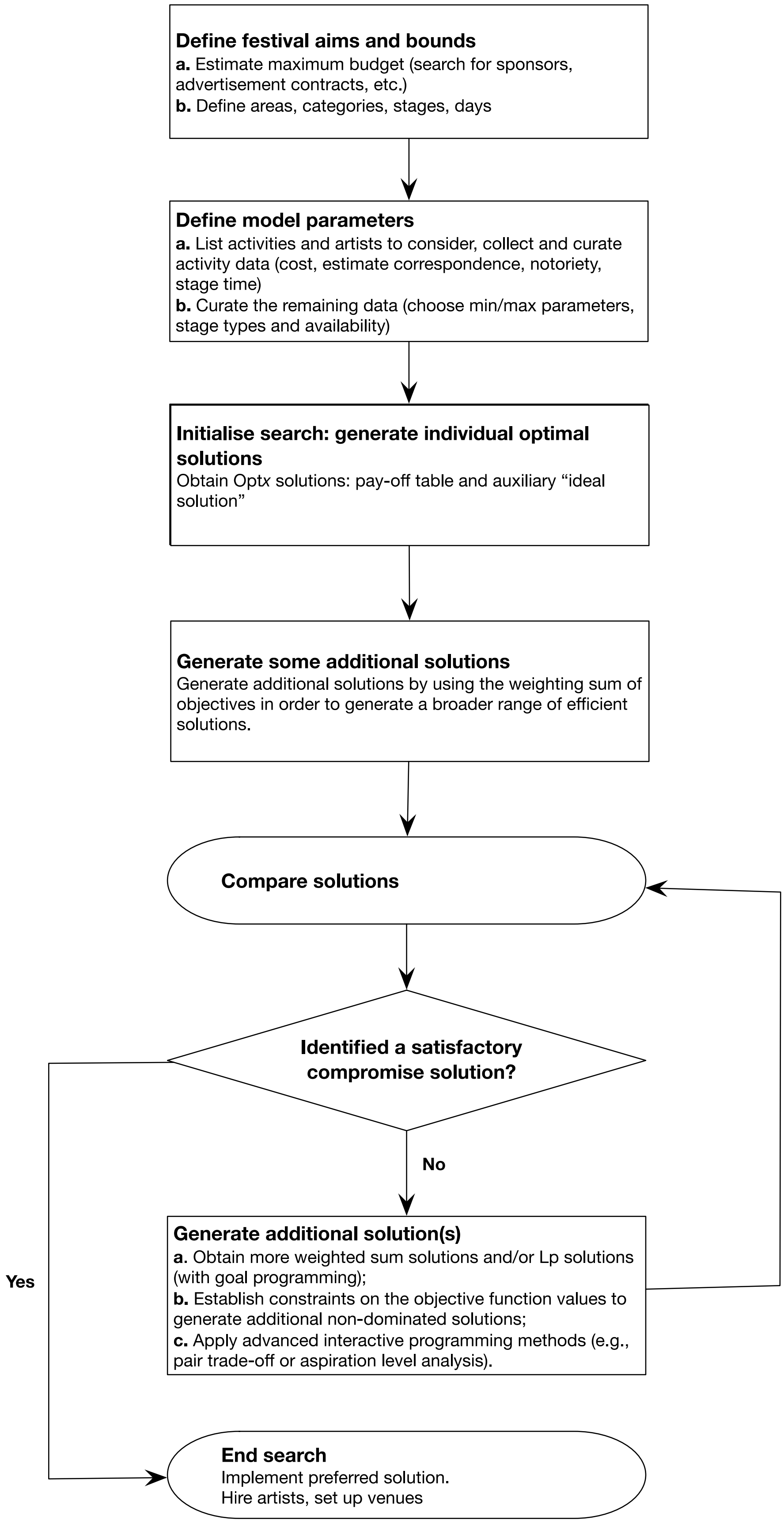
The L_1 distance to the ideal is the sum of the (relative) distances of each objective to its goal value (in this case the optimum), whereas the L_∞ distance is the maximum (relative) distance among all the objectives to their goal values. A 'goal programming solution' is then the solution that minimizes the L_1 (or L_∞) distance to the goal. If a goal other than the ideal were sought, it would suffice to replace Opt_i for the other goal values in (16).

The weighted sum method and goal programming are commonly used in multi-objective optimization to obtain solutions for subsequent trade-off analysis between the objectives, and those were the two methods this research used. Being a linear model, both types of solution can be obtained from existing MILP solvers. Other specialized methods may be used to generate solutions of the Pareto front, such as e.g., the constraint method (Cohon, 1978), in which the decision maker establishes upper/lower limits for all but one of the objectives, which is then maximized/minimized subject to those limits. However, this method is usually not very practical for three or more objectives.

Searching for further solutions

Should the decision maker wish to look for more solutions, she can investigate regions of solution space in the neighborhood of any particular solution which shows good compromise between the objectives, generating additional (similar) solutions which may turn out even more appealing. Such a closer look may help deciding between candidate solutions or suggest directions for generating additional solutions. This iterative procedure, whereby the decision maker interactively explores the solution space looking for one solution which will ultimately be implemented, is common in multi-objective optimization problems. Advanced interactive programming methods, such as those based on aspiration levels or pair trade-off analysis (Stewart, 1999), may also be used to further guide the decision maker in the search for a preferred compromise solution. If such a procedure is needed, the choice of which one will depend on what the decision-maker is aiming at, as they have different purposes. For instance, if the decision maker is interested in a particular solution but wishes to have a slightly better value in a certain objective, the aspiration level procedure can be used to look for candidates in the vicinity of that solution. Figure 1 provides a possible flowchart for the interactive approach, adequate for the festival planning model.

The alternative of generating the entire set of efficient solutions is usually recognized as a daunting task and, as the number of objectives increases, analyzing the trade-offs among them and among the various efficient alternatives becomes more difficult (Cohon, 1978; Zeleny, 1982), if not outright intractable.



1

2 Figure 1. Flowchart for selecting a solution interactively.

4. Case study

To demonstrate the model, a case study was generated which simulates a festival suitable for a mid-sized city. The case study was inspired by the cultural scene of Coimbra, Portugal (circa 140,000 inhabitants), a city with higher education and healthcare as main economic activities. Coimbra attracts many visitors from nearby districts that come to watch the shows and often hosts multiple-day festivals of various kinds (e.g., religious, folk, students' festivals, etc.). From time to time, Coimbra applies for cultural capital status and the case study simulates what a week under that status might look like in terms of cultural offer, when optimized. Stages and cultural venues of the city correspond to existing locations and real artists of various genres were considered for the activities, with a budget based on their customary charges. The case study festival is thus realistic and could actually be carried out. A summary of the data is presented in Tables 4 and 5 below.

Table 4. Case study data summary.

Days	**Areas**	**Categories**	**Activities**	**Stages**	**Max budget (total)**
5	4	35	100	7	350,000 EUR

Table 5. Areas, nr. of categories per area, and stages.

Area code	**Area name**	**Categories**
1	Music	7
2	Dance	4
3	Theatre	6
4	Media Art	18

Stage code	**Stage name**	**Max places**
1	TAGV Auditorium	800
2	Theatre Cerca de S. Bernardo	400
3	Visual Arts Centre	150
4	Museum Casa das Caldeiras	200
5	Chapitô at Jardim da Sereia	350
6	Boulevard of Jardim da Sereia	4000
7	TAGV Foyer	100

Out of the 35 categories, 28 have $N_c^{mC} > 0$, covering all areas. Variety in parameter values was also sought, so that the case study would have a general character and attract a wide range of spectators. In terms of problem size, the case study can be characterized as a mid-sized instance, as both larger (more activities) and longer festivals (more days) exist in practice, as well as smaller and shorter ones.

Results

The model was setup and run for the case study. Solutions were derived with the weighted sum and goal programming methods, using the CPLEX 22.1 solver on an Apple M1 processor. This yielded Table 6 below, whose first five rows form the pay-off table. Solutions in rows 6 to 11 were generated using the weighted sum method, and solutions in rows 12 and 13 were generated with goal programming. The pay-off and other solutions of Table 6 assist the decision maker in analyzing the trade-offs between the various solutions. For the solution in each row, columns indicate objective values, with ΔL the solution's distance to the ideal, as measured by (16ab). The solution 'equal weights' corresponds to $|w_i| = 0.2, \forall_i$. The solutions 'focus O*x*' are weighted sum solutions with objective *x* weighting twice as much as each of the remaining ones and are presented as examples of a broader exploration of the solution space. The entry values, which are underlined and in bold, form the ideal solution and the entries in italics form the anti-ideal (nadir), another reference point with the worst values in each objective.

Table 6. Pay-off table (rows Opt*x*) and additional solutions.

	Solution	Cost (€)	Corr.	Renown	Complex.	Stage occ. (h)	ΔL_1 (%)	ΔL_∞ (%)
1	Opt1 (min)	**<u>236,750</u>**	*10,164*	*12.9*	16.1	*180.7*	127.5	52.0
2	Opt2 (max)	349,250	**<u>21,152</u>**	18.4	22.1	235.4	114.3	47.5
3	Opt3 (max)	*349,700*	18,846	**<u>19.3</u>**	*22.9*	254.0	120.1	47.7
4	Opt4 (min)	246,250	10,237	13.1	**<u>15.5</u>**	193.6	122.2	51.6
5	Opt5 (max)	349,400	15,168	17.9	22.7	**<u>294.6</u>**	130.0	47.6
6	Equal weights	320,050	19,182	17.4	20.2	254.7	97.9	35.2
7	Focus O1 (2,1,1,1,1)/6	260,100	12,940	14.6	17.0	217.9	108.8	38.8
8	Focus O2 (1,2,1,1,1)/6	347,350	20,751	18.3	21.5	267.0	101.3	46.7
9	Focus O3 (1,1,2,1,1)/6	336,650	19,657	18.4	21.2	267.9	99.3	42.2
10	Focus O4 (1,1,1,2,1)/6	281,600	15,768	15.3	17.6	220.9	103.5	25.5
11	Focus O5 (1,1,1,1,2)/6	346,900	19,464	18.5	21.4	279.3	101.5	46.5
12	Goal L_1	320,050	19,182	17.4	20.2	254.7	97.9	35.2
13	Goal L_∞	287,550	16,618	15.4	18.7	231.7	105.3	21.5

A quick look at Table 6 shows that the Opt*x* are extreme solutions that optimize a particular objective at the expense of considerable degrades of the other ones. Weighted sum and goal programming solutions are more balanced solutions that nonetheless exhibit some variety among themselves. Further interpretation of Table 6 results and the types of line ups they yield is done in the discussion section. In addition to the table solutions, given the low CPU time required (see below), a total of 235 supplementary weighted sum solutions were derived, spanning a wider set of the weight space. These additional solutions allow for a deeper, more precise understanding of how solutions behave as weights change and are explored in Appendix B. Exploration of these solutions may also lead to the decision maker finding a satisfactory one, waiving the need for iterative solution-seeking procedures.

Of the total 248 runs, all finished in 1-30 seconds CPU time, except for Opt2 and Goal L_∞, which took respectively 3 and 15 minutes to obtain. In the end of section 5 some computational considerations are discussed.

5. Discussion

Focusing first on Table 6, solution Opt1 (minimize cost) is the cheapest one which satisfies all model constraints. Solutions Opt2 and Opt3 show that maximizing the correspondence between places and audience expectation is not the same as maximizing how renowned the artist or act may be. The two are however similar objectives, so it is not surprising that their optima have relatively similar solution values for all objectives. Solution Opt4 (minimize complexity) is similar to Opt1 because minimizing logistic complexity amounts to choosing the simplest activities possible while respecting the constraints. Finally, Opt5 is limited essentially by logistic and budgetary constraints, as the total stage time available is 464 hours, of which only circa 63% can ever be occupied.

FocusO*x* are weighted sum solutions which span a small subset of the Pareto front, but exhibit some coverage of the solution space, as individual objective values vary between close to ideal and nadir values. Their quality, as measured by distance to the ideal, is, as expected, better than Opt*x* solutions, because weighted sum solutions are compromise solutions rather than extreme ones.

The two goal programming solutions also exhibit some variety between them, further showing that the decision maker has some freedom of choice between the various solutions. Notice that the L_1 solution is equal to the equal weights one. It may be checked this is a consequence of the normalization formula (15).

To help visualizing the trade-offs between solutions, the BAGAL (best against least) diagram of Figure 2 can be used (Coutinho-Rodrigues et al., 1997). This diagram allows for a quick, intuitive comparison of solutions and can be helpful to decide which direction to go in search for more compromise solutions, should none thus far prove satisfactory. The diagram was normalized as ratio difference to the ideal by replacing x_i objective values by $x_i \rightarrow \frac{x_i - \mathrm{Opt}_i}{\mathrm{Nadir}_i - \mathrm{Opt}_i}$. The closer the 5-sided polygon is to the central pentagon, the better the solution is.

Inspection of the BAGAL diagram shows that Goal L_∞ may be considered a good compromise solution, with FocusO4 a similar choice. FocusO2, FocusO3 and FocusO5 are similar among themselves: they are expensive but provide good-quality lineups. FocusO1 is the cheapest solution, but it comes at the expense of the quality of the lineup. The goal L_1/equal weights solution interpolates between the cheap and expensive solution types.

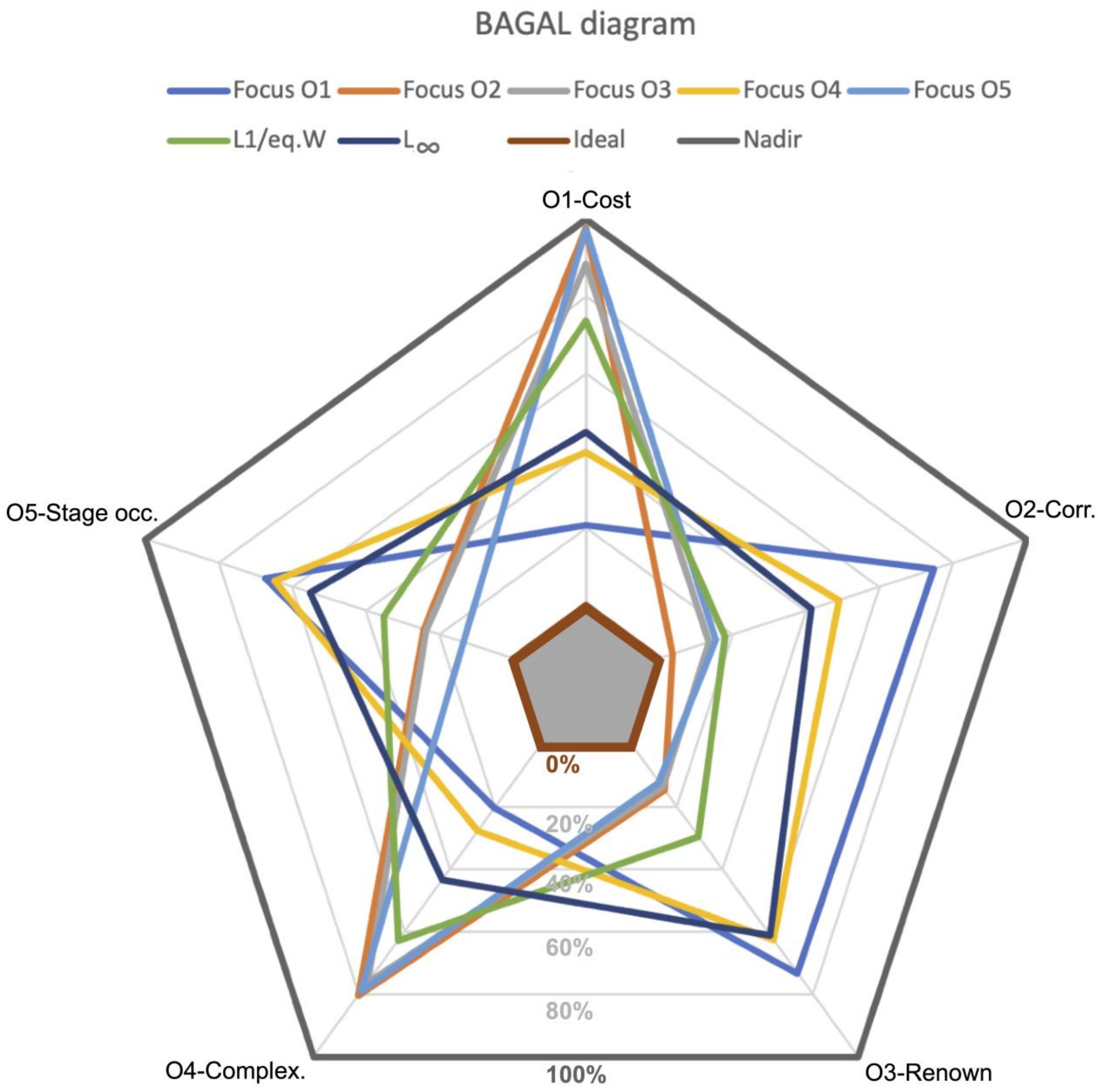


Figure 2. BAGAL diagram of normalized distances to the ideal for FocusOx and L_p solutions. Scale: %distance to ideal (smaller is better).

Ultimately, Table 6 solutions and the BAGAL diagram evidence trade-offs between solutions that reflect the nature of the festival planning problem: O2, O3 and O5 push for filling stages and hiring the most renowned artists. Since these typically have higher costs and more complex logistics, quality lineups degrade scores in objectives O1 and O4. In turn, improving O1, O4 scores degrades O2, O3 and O5 scores. The non-extreme solutions of Table 6 represent optimized compromises between these trade-offs, which are usually what the decision maker looks for.

In evaluating a solution, the decision maker may also want to look at its profile, i.e., how many activities get lined up for each category, and which artists are selected. This helps understanding how the different solutions look like in practice and how they fit the festival context. Tables 7 and 8 below show a breakdown of the profiles for Table 6 solutions, ordered by cost.

Table 7. Solutions profile for Table 6 – category lineup vs. cost.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1			Solution ID	Opt1	Opt4	FocusO1	FocusO4	Linf	L1	Eq_W	FocusO3	FocusO5	FocusO2	Opt2	Opt5	Opt3
2	Category	Area	Category name \ Cost (€)	236750	246250	260100	281600	287550	320050	320050	336650	346900	347350	349250	349400	349700
3	1	Music	Pop/Rock	2	2	2	3	3	3	3	3	3	3	3	2	3
4	2	Music	Folk	0	0	0	0	0	0	0	0	0	1	1	0	0
5	3	Music	World Music	1	1	1	1	2	2	2	2	2	2	2	2	2
6	4	Music	Jazz	1	1	1	1	1	1	1	2	1	2	2	1	2
7	5	Music	Hip-Hop	0	0	1	1	1	1	1	1	1	1	1	1	1
8	6	Music	Contemporary Folk	1	1	1	1	1	1	1	1	1	1	1	1	1
9	7	Music	Classical Music	1	1	1	1	1	1	1	1	1	1	1	2	1
10	8	Dance	Contemporary Dance	1	1	1	1	1	1	1	1	1	1	1	2	2
11	9	Dance	Classical Ballet	1	1	1	1	1	1	1	1	1	1	1	1	1
12	10	Dance	Ballroom	0	0	0	0	0	0	0	0	0	0	0	0	1
13	11	Dance	Folk Dance	1	1	1	1	1	1	1	1	1	1	1	1	1
14	12	Theatre	Classical Theatre	1	1	1	1	1	1	1	1	1	1	1	2	2
15	13	Theatre	Interactive Theatre	2	2	2	2	2	2	2	2	2	2	2	2	2
16	14	Theatre	Musical Theatre	0	0	0	0	0	0	0	0	1	0	0	1	0
17	15	Theatre	Puppet Show	1	1	1	1	1	2	2	2	2	2	2	2	2
18	16	Theatre	Historic Reenactment	1	1	1	1	1	1	1	1	1	1	1	1	1
19	17	Theatre	Street Performance	1	1	1	1	1	1	1	2	2	2	1	2	2
20	18	Media Art	Cinema	1	1	1	1	1	1	1	1	1	1	1	1	1
21	19	Media Art	Video Installations	1	1	1	1	1	1	1	1	1	1	1	1	1
22	20	Media Art	Painting	1	1	1	1	1	1	1	1	1	1	1	1	1
23	21	Media Art	Cartoon/Drawings	2	2	2	2	2	2	2	2	2	2	2	2	2
24	22	Media Art	Photography	1	1	1	1	1	1	1	1	1	1	1	1	1
25	23	Media Art	Sculpture	0	0	0	0	0	0	0	0	0	0	0	1	0
26	24	Media Art	Body Art	1	1	1	1	1	1	1	1	1	1	1	1	1
27	25	Media Art	Multimedia Installations	2	2	2	2	2	2	2	2	2	2	2	2	2
28	26	Media Art	Web-Art	1	1	1	1	1	1	1	1	1	1	1	1	1
29	27	Media Art	Holographic Art	0	0	0	0	0	1	1	1	1	1	1	0	0
30	28	Media Art	Clown Show	1	1	1	1	1	2	2	2	2	2	2	2	2
31	29	Media Art	Fire Performance	1	1	1	1	1	2	2	2	2	2	1	2	2
32	30	Media Art	Ventriloquism	0	0	0	0	1	1	1	1	1	1	1	1	1
33	31	Media Art	Urban Crafts	2	2	3	3	3	3	3	3	3	3	3	3	3
34	32	Media Art	Tatoos	1	1	1	1	1	1	1	1	1	1	1	1	1
35	33	Media Art	DJ/VJ	1	1	1	1	1	1	1	2	2	1	2	2	2
36	34	Media Art	Creative Writing	1	1	1	1	1	1	1	1	1	1	1	1	1
37	35	Media Art	Miscellaneous Video-Art	1	1	1	1	1	1	1	1	1	1	1	1	1

In Tables 7 and 8, rows are categories (activities) and columns the solutions. The numbers indicate how many times the respective category (activity) gets lined up in the respective solution. Category names correspond to the artists' art genre and activity names were anonymized, as they would otherwise include real artist names. In Table 8, activities which never get lined up were omitted (35 out of 100).

Analyzing Table 7 reveals that all categories feature in at least one solution and some categories always feature. However, some, but not all, always feature due to $N_{ac}^{mA} \geq 1$ and $N_{c}^{mC} \geq 1$ parameters. It is interesting to note that some categories, e.g., #2, #10, and #23, only feature in the more extreme Opt*x* solutions, which are unlikely to be selected. This may happen because of low renown of that category but also if artists in that category are not competitive, e.g., too expensive to hire or too complex to stage. If the festival context is such that the decision maker wishes to always have representatives of those categories, she would need to set the respective N_{c}^{mC} parameters to 1 or consider more artists. For instance, one can argue that a festival on a city of cultural capital status should hold at least one sculpture exhibition (#23), which currently only happens for the extreme Opt5 solution. This suggests setting that category's N_{c}^{mC} to 1 and rerun the model. Likewise, such a festival may not necessarily need to hold fire performances (#29), so that category's N_{c}^{mC}, which is 1 for the case study, may be lowered to 0.

Moving to Table 8, of the 100 activities, only 65 ever get lined up. Of these, 21 feature in all solutions (8 due to $N_{ac}^{mA} \geq 1$). Again, it is seen the Opt*x* are considerably extreme, as 17 activities only get lined up for these solutions. On the other hand, for the other, more balanced, solutions, 27 activities always get lined up at least once, so the festival management team is well-advised to book the corresponding artists well in advance. Only two star activities get lined up (#2 and #79), but more exist in the 35 activities that are never lined up. Having more star activities would require setting $N_{ac}^{mA} \geq 1$ for those activities. However, they may also arise *per se* in solutions besides those of Table 6.

Looking at tables 7 and 8 together, and referring to the presence/absence of categories and activities in the solutions, the picture is both of some persistence and moderate variety, which is arguably desirable for a one-week festival in a city of cultural capital status. All categories are present, and there is some variation as to which activities get lined up inside each category. As with most MILP models, solution profiles and their overall characteristics depend on the input data. The case study data, which is realistic, led to solutions that are neither too predictable nor restrictive, making it reasonable to select one of the FocusO*x* or goal programming solutions for implementation. Should the decision maker still not be satisfied with any of those solutions, they make good starting points for the interactive procedure of looking for other, more satisfactory ones.

Given the computational efficiency in deriving solutions, it was possible to generate many additional weighted sum solutions and study their spread in the space of objectives. This finer-grained analysis is presented in Appendix B and enables the decision maker to have a better understanding of the problem solution structure and trade-offs possible between the various objectives.

Table 8. Solutions profile for Table 6 – activity lineup vs. cost (* denotes a star activity).

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1			Solution ID	Opt1	Opt4	FocusO1	FocusO4	Linf	L1	Eq_W	FocusO3	FocusO5	FocusO2	Opt2	Opt5	Opt3
2	Name	Area	Category \ Cost (€)	236750	246250	260100	281600	287550	320050	320050	336650	346900	347350	349250	349400	349700
3	Activity 2*	Music	Pop/Rock	1	1	1	1	1	1	1	1	1	1	1	1	1
4	Activity 3	Music	Pop/Rock	0	0	0	1	1	1	1	1	1	1	1	0	1
5	Activity 5	Music	Pop/Rock	1	1	1	1	1	1	1	1	1	1	1	1	1
6	Activity 7	Music	Folk	0	0	0	0	0	0	0	0	0	1	1	0	0
7	Activity 8	Music	World Music	0	0	0	0	1	1	1	1	1	1	1	1	1
8	Activity 10	Music	World Music	1	1	1	1	1	1	1	1	1	1	1	1	1
9	Activity 11	Music	Jazz	1	1	1	1	1	1	1	2	1	2	2	1	2
10	Activity 14	Music	Hip-Hop	0	0	1	1	1	1	1	1	1	1	1	1	1
11	Activity 16	Music	Contemp. Folk	1	1	1	1	1	1	1	1	1	1	1	1	1
12	Activity 19	Music	Classical	0	0	0	0	0	0	0	0	0	0	1	0	0
13	Activity 20	Music	Classical	1	1	1	1	1	1	1	1	1	1	0	2	1
14	Activity 22	Dance	Contemporary	1	1	1	1	1	1	1	1	1	1	1	1	1
15	Activity 23	Dance	Contemporary	0	0	0	0	0	0	0	0	0	0	0	1	0
16	Activity 24	Dance	Contemporary	0	0	0	0	0	0	0	0	0	0	0	0	1
17	Activity 26	Dance	Classical Ballet	1	1	1	1	1	1	1	1	1	1	1	1	1
18	Activity 30	Dance	Ballroom	0	0	0	0	0	0	0	0	0	0	0	0	1
19	Activity 31	Dance	Folk	1	0	1	1	1	1	1	1	1	1	1	1	1
20	Activity 32	Dance	Folk	0	1	0	0	0	0	0	0	0	0	0	0	0
21	Activity 33	Theatre	Classical	1	0	1	1	1	1	1	1	1	1	0	1	0
22	Activity 34	Theatre	Classical	0	1	0	0	0	0	0	0	0	0	0	0	0
23	Activity 35	Theatre	Classical	0	0	0	0	0	0	0	0	0	0	0	1	1
24	Activity 36	Theatre	Classical	0	0	0	0	0	0	0	0	0	0	1	0	1
25	Activity 37	Theatre	Interactive	0	0	0	0	0	0	0	0	0	0	1	0	0
26	Activity 38	Theatre	Interactive	2	2	2	2	2	2	2	2	2	2	1	2	2
27	Activity 39	Theatre	Musical	0	0	0	0	0	0	0	0	1	0	0	0	0
28	Activity 41	Theatre	Musical	0	0	0	0	0	0	0	0	0	0	0	1	0
29	Activity 42	Theatre	Puppet	0	0	1	1	0	1	1	1	1	1	1	1	1
30	Activity 43	Theatre	Puppet	0	0	0	0	1	1	1	1	1	1	1	1	1
31	Activity 44	Theatre	Puppet	1	1	0	0	0	0	0	0	0	0	0	0	0
32	Activity 46	Theatre	Hist. Reenactment	1	1	1	1	1	1	1	1	1	1	1	1	1
33	Activity 47	Theatre	Street performance	1	1	1	1	1	1	1	1	1	1	1	1	1
34	Activity 48	Theatre	Street performance	0	0	0	0	0	0	0	1	0	1	0	0	0
35	Activity 49	Theatre	Street performance	0	0	0	0	0	0	0	0	1	0	0	1	1
36	Activity 50	Theatre	Cinema	0	1	1	1	0	1	1	1	1	1	1	0	1
37	Activity 51	Theatre	Cinema	0	0	0	0	0	0	0	0	0	0	0	1	0
38	Activity 53	Theatre	Cinema	1	0	0	0	1	0	0	0	0	0	0	0	0
39	Activity 57	Media art	Video installations	1	1	1	1	1	1	1	1	1	1	1	1	1
40	Activity 58	Media art	Painting	1	1	1	1	1	1	1	1	1	1	1	1	1
41	Activity 61	Media art	Cartoon/Drawings	1	1	1	1	1	1	1	1	1	1	1	1	1
42	Activity 63	Media art	Cartoon/Drawings	1	1	1	1	1	1	1	1	1	1	1	1	1
43	Activity 64	Media art	Photography	1	1	1	1	1	1	1	1	1	1	1	1	1
44	Activity 68	Media art	Sculpture	0	0	0	0	0	0	0	0	0	0	0	1	0
45	Activity 69	Media art	Body art	1	0	0	0	1	0	0	0	0	0	0	0	0
46	Activity 70	Media art	Body art	0	1	1	1	0	1	1	1	1	1	1	1	1
47	Activity 71	Media art	Multimedia	1	1	1	1	1	1	1	1	1	1	1	1	1
48	Activity 73	Media art	Multimedia	0	0	0	0	0	0	0	0	0	0	0	1	0
49	Activity 74	Media art	Multimedia	1	1	1	1	1	1	1	1	1	1	1	0	1
50	Activity 76	Media art	Web-art	1	1	1	1	1	1	1	1	1	1	1	1	1
51	Activity 78	Media art	Holographic	0	0	0	0	0	1	1	1	1	1	0	0	0
52	Activity 79*	Media art	Holographic	0	0	0	0	0	0	0	0	0	0	1	0	0
53	Activity 80	Media art	Clown show	1	1	1	1	1	1	1	1	1	1	1	1	1
54	Activity 81	Media art	Clown show	0	0	0	0	0	0	0	0	0	0	1	0	0
55	Activity 82	Media art	Clown show	0	0	0	0	0	1	1	1	1	1	0	1	1
56	Activity 83	Media art	Fire performance	0	0	0	0	0	1	1	1	1	1	0	1	1
57	Activity 84	Media art	Fire performance	1	1	1	1	1	1	1	1	1	1	1	1	1
58	Activity 86	Media art	Ventriloquism	0	0	0	0	1	1	1	1	1	1	1	1	1
59	Activity 87	Media art	Urban crafts	0	2	3	3	3	3	3	3	3	3	0	3	0
60	Activity 90	Media art	Urban crafts	2	0	0	0	0	0	0	0	0	0	3	0	3
61	Activity 93	Media art	Tatoos	1	1	1	1	1	1	1	1	1	1	1	1	1
62	Activity 94	Media art	DJ/VJ	0	0	1	0	0	1	1	1	1	1	1	0	1
63	Activity 95	Media art	DJ/VJ	0	1	0	1	0	0	0	0	0	0	0	1	0
64	Activity 96	Media art	DJ/VJ	1	0	0	0	1	0	0	1	1	0	1	1	1
65	Activity 97	Media art	Creative writing	1	1	1	1	1	1	1	1	1	1	1	1	1
66	Activity 99	Media art	Misc. Video-art	0	1	0	1	0	1	1	1	0	1	1	0	1
67	Activity 100	Media art	Misc. Video-art	1	0	1	0	1	0	0	0	1	0	0	1	0

The decision maker, after using all the aids, then must pick a particular solution (or continue generating additional solutions), knowing that, regardless of the actual solution picked, all dimensions of reality have been considered in the process.

In Appendix A a possible flyer for the case study festival is presented, made from the Goal L_∞ solution, combining artistic quality, match to spectator expectations, and management and financial issues. The final decision over the festival's concrete program will ultimately be of the responsibility of the management team and its success up to performance of the artists, knowing that this success is potentiated by the choices suggested by the model.

Computational considerations

For the case study it was possible to terminate all calculations. Given the computational efficiency of MILP solvers as of the time of writing, it is likely that solutions can be derived in reasonable time even for very large festivals. To test the model on larger problem sizes, two more instances were generated. The first extended the case study to about twice the size: 12 days, 60 categories, 20 stages, 8 areas, and 740,000 € budget. In making the extension, realistic activities and prices were considered. The second instance consisted of 15 days, 100 categories, 25 stages, 12 areas, and a 2,500,000 € budget. Data for this second instance was randomly generated, conditioned only to feasibility.

For both instances, solutions of Table 6 could be derived within CPU times comparable to those of the case study, i.e., 1-30 seconds. Some runs however carried on and were terminated at 30 min runtime, exhibiting at that point a gap < 0.1% between the best integer and real solutions (one case had a gap of 0.33%). On these runs a good solution, at or near the gap, was found in just a few seconds and subsequent improvements were very small or non-existent. This behavior is usual with MILP models (see e.g., Domínguez-Martín et al. [2024] or Espejo et al. [2023] for recent examples) and, albeit solutions at termination time may not be guaranteed non-dominated, they are otherwise close enough to be considered by the decision maker as valid planning proposals. It does however warn that advanced interactive approaches might run into difficulties in large problems, as deriving many solutions could become time-consuming.

Model limitations and possible variations

The model's main limitation is that it does not consider revenues, so it is best applied to contexts where budgets are constrained and/or costs are to be minimized, rather than contexts where more profitable solutions are preferred. Upgrading the model to include revenues would allow for changing objective O1 into 'maximize festival profit', but that would require modeling supply and demand in some sensible way. A possible variation that may appeal to privately-funded festivals would be to estimate revenues based on fixed ticket prices (e.g., past prices) and change O1 to $\max O_1 = \sum_d \sum_s \sum_c \sum_a (R_{ac}^A - C_{ac}^A) x_{acsd}$, with R_{ac}^A the estimated revenue of activity a of category c. Dropping the budget constraints (11) is also a possibility in this model variant, as leaving them might hinder discovering high cost, but very profitable solutions. An example would be, e.g., hiring an extremely famous but expensive artist: a private organizer might be willing to risk this option if the revenue expectancy is attractive. In any case, running the model in this alternative formulation would expectably lead to solutions that shift from the lower cost activities to the higher profit ones.

More precise revenue estimations might need including ticket price as a model variable, as well as a stage dependency of revenues, as the number of places available might impact attendance. These considerations lead to more complex model variations and are left for future work. One should, however, keep in mind that finding relations between price, supply, and demand is difficult task and it is possible that a reliable relation, even if found, could cause the model to become non-linear, in which case metaheuristics would be needed to derive solutions. If, on the other hand, such relations cannot be found (or are found but are not precise enough), there is always the option to run the model for a few different estimates of ticket prices and place occupancy rates and compare solutions. The model, in its present formulation, follows a different approach: it does not consider price/supply/demand issues and relies on objectives O2 and O3 to obtain quality line ups, leaving ticket pricing for subsequent stages of festival management. It is worth noting that the model's approach may be appealing even to private sector festival organizations, given it always provides quality line ups.

Another limitation is that parameters relating to objectives O2, O3 and O4 are subjective and thus prone to imprecisions. For O2 and O3 parameter values could, perhaps, be improved upon using specialized surveys or looking at past attendance. For O4, a possible objective quantification might be $W_{ac}^{LA} = p_{ac}^{LA} t_{ac}^{LA}$, with p_{ac}^{LA} the probability of a delay in stage preparation for activity a of category c and t_{ac}^{LA} the corresponding average delay time (both derived, e.g., from past shows).

6. Summary and future work

This article presented a multi-objective model for the planning large-scale festivals composed of multiple simultaneous activities, spanning several days. The budgets and spectator numbers usually involved in this type of event make it important to carefully plan such festivals, matching artistic quality to audience expectations while keeping financial and logistic aspects under control.

The model proposed takes all these dimensions of reality into account, making it a decision support tool to assist event planners and managers in providing audiences with optimized festival lineups, in the fields where such events are typically held. It is especially suited for publicly funded festivals, as these typically deal with limited budgets or wish to minimize costs, and often worry about the multiple organizing aspects this research considers. To best of the authors' knowledge, this is one of the first contributions to the literature on multi-objective decision support for festival management and event tourism.

Optimal lineups have the potential to attract larger audiences to festivals, increase spectator and tourist flows, and maximize comeback rates, fostering all the benefits for the local community that come from the presence of a high number of people attending the shows. Flexible decision-aid tools for generating and exploring optimal lineups are therefore a plus-value for festival management that may yield interesting returns, especially if organizational and financial aspects are also considered, as they are in the model proposed here. The bigger and more complex the festival is, the higher the chances for gains coming from lineup optimization are, and the more profitable the use of the proposed decision-aid tool becomes.

The model herein presented is a first step in the development of mathematical festival planning tools and is open to improvement. As future work, possibly the most interesting direction would be to develop a supply-demand model which could include ticket prices and other income sources, evolving the model into profit-oriented variations, which would appeal to festival organizers of the private sector. Another possibility would be to change the renown objective into maximize specific renown, i.e., the quotient between total renown and the number of activities to line up. This would sidestep solutions with many cheap, but lesser activities, replacing them with possibly more impactful artists. However, such a change would also make the model non-linear and to obtain solutions one would either need to find a linearization procedure or use some metaheuristic method. Possible model-specific upgrades could be to make logistic complexity depend on stage and/or add preferences to stage occupation (this would slightly modify eqs. 4 and 5). We hope to address some of these lines of research in the near future.

Declaration of competing interests

None.

Acknowledgements

This work was supported by the Portuguese Foundation for Science and Technology under the project grant UIDB/00308/2020 with the DOI 10.54499/UIDB/00308/2020. Datasets are available on request.

References

Abedinnia, H., Glock, C.H. & Schneider, M.D. (2017). Machine scheduling in production: A content analysis. *Applied Mathematical Modelling*, 50, 279-299. https://doi.org/10.1016/j.apm.2017.05.016

Afshar-Nadjafi, B. (2021). Multi-skilling in scheduling problems: A review on models, methods and applications. *Computers and Industrial Engineering*, 151, 107004. https://doi.org/10.1016/j.cie.2020.107004

Allen, J., O'Toole, W., Harris, R. & McDonnell, I. (2010). *Festival and Special Event Management*, 5th ed. John Wiley & Sons. ISBN: 978-1742164618.

Arcodia, C. & Whitford, M. (2006). Festival attendance and development of social capital. *Journal of Convention and Event Tourism*, 8(2), 1-18. https://doi.org/10.1300/J452v08n02_01

Arellano, A. (2011). A history of Quebec-branded: the staging of the New France festival. *Event Management*, 15(1), 1-12. https://doi.org/10.3727/152599510X12901814777907

Baumann, R., Matheson, V. & Muroi, C. (2009). Bowling in Hawaii: examining the effectiveness of sports-based tourism strategies. *Journal of Sport Economics*, 10(1), 107-123. https://doi.org/10.1177/1527002508327401

Boatwright, P., Basuroy, S. & Kamakura, W. (2007). Reviewing the reviewers: The impact of individual film critics on box office performance. *Quantitative Marketing and Economics*, 5, 401-425. https://doi.org/10.1007/s11129-007-9029-1

Bramwell, B. (1997). Strategic planning before and after a mega-event. *Tourism Management*, 18(3), 167-176. https://doi.org/10.1016/S0261-5177(96)00118-5

Chalip, L. & Leyns, A. (2002). Local business leveraging of a sport event: managing an event for economic benefit. *Journal of Sport Management*, 16, 132-158. https://doi.org/10.1123/jsm.16.2.132

Chalip, L. & McGuirty, J. (2004). Bundling sport events with the host destination. *Journal of Sport Tourism*, 9(3), 267-282. https://doi.org/10.1080/1477508042000320241

Chang, J. (2006). Segmenting tourists to aboriginal cultural festivals: An example in the Rukai tribal area, Taiwan. *Tourism Management*, 27(6), 1224-1234. https://doi.org/10.1016/j.tourman.2005.05.019

Choi, K., Kang, H.J. & Kim, C. (2021). Evaluating the efficiency of Korean festival tourism and its determinants on efficiency change: Parametric and non-parametric approaches, *Tourism Management*, 86, 104348. https://doi.org/10.1016/j.tourman.2021.104348

Coelho, J., & Vanhoucke, M. (2011). Multi-mode resource-constrained project scheduling using RCPSP and SAT solvers. *European Journal of Operational Research*, 213(1), 73-82. https://doi.org/10.1016/j.ejor.2011.03.019

Cohon, J. (1978) *Multiobjective Programming and Planning*. New York: Academic Press. ISBN: 0121783502.

Coutinho-Rodrigues, J., Current, J.R., Clímaco, J. & Ratick, S. (1997). An interactive spatial decision support system for multiobjective HAZMAT location-routing problems. *Transportation Research Record*, 1602, 101-109. https://doi.org/10.3141/1602-15

Domínguez-Martín, B., Hernández-Pérez, H., Riera-Ledesma, J. & Rodríguez-Martín, I. (2024). A branch-and-cut algorithm for the one-commodity pickup and delivery location routing problem. *Computers and Operations Research*, 161, 106426. https://doi.org/10.1016/j.cor.2023.106426

Ehrgott, M. (2005). *Multicriteria Optimization*, 2nd Ed. Springer. ISBN 978-3642059759.

Espejo, I., Marín, A., Muñoz-Ocaña J.M. & Rodríguez-Chía, A.M. (2023). A new formulation and branch-and-cut method for single-allocation hub location problems. *Computers and Operations Research*, 155, 106241. https://doi.org/10.1016/j.cor.2023.106241

Ferdinand, N. & Williams, N.L. (2013). International festivals as experience production systems. *Tourism Management*, 34, 202-210. https://doi.org/10.1016/j.tourman.2012.05.001

Ford, R., Peeper, W. & Gresock, A. (2009). Friends to grow and foes to know: using a stakeholder matrix to identify management strategies for convention and visitors bureaus. *Journal of Convention and Event Tourism*, 10(3), 166-184. https://doi.org/10.1080/15470140903127176

Fotedar, S., Strömberg, A.-B. & Almgren, T. (2023). Bi-objective optimization of the tactical allocation of job types to machines: mathematical modeling, theoretical analysis, and numerical tests. *International Transactions in Operational Research*, 30, 3479-3507. https://doi.org/10.1111/itor.13180

Gannon, M., Taheri, B. & Olya, H. (2019). Festival quality, self-connection, and bragging. *Annals of Tourism Research*, 76, 239-252. https://doi.org/10.1016/j.annals.2019.04.014

García, B. (2001). Enhancing Sport Marketing through Cultural and Arts Programs: Lessons from the Sydney 2000 Olympic Arts Festivals. *Sport Management Review*, 4, 193-219. https://doi.org/10.1016/s1441-3523(01)70075-7

Gawiejnowicz, S. (2020). A review of four decades of time-dependent scheduling: main results, new topics, and open problems. *Journal of Scheduling*, 23, 3-47. https://doi.org/10.1007/s10951-019-00630-w

Getz, D. (2008) Event tourism: Definition, evolution, and research. *Tourism Management*, 29(3), 403-428. https://doi.org/10.1016/j.tourman.2007.07.017

Getz, D. (2016). *Event studies: Theory, research and policy for planned events, 3rd edition*. Oxford: Elsevier. ISBN 978-1315708027 (eBook)

Getz, D. & Page, S.J. (2016). Progress and prospects for event tourism research. *Tourism Management*, 52, 593-631. https://doi.org/10.1016/j.tourman.2015.03.007

Grappi, S. & Montanari, F. (2011). The role of social identification and hedonism in affecting tourist re-patronizing behaviours: The case of an Italian festival. *Tourism Management*, 32(5), 1128-1140. https://doi.org/10.1016/j.tourman.2010.10.001

Gursoy, D. & Kendall, K.W. (2006). Hosting mega events: Modeling Locals' Support. *Annals of Tourism Research*, 33(3), 603-623. https://doi.org/10.1016/j.annals.2006.01.005

Hartmann, S. & Briskorn, D. (2010). A survey of variants and extensions of the resource-constrained project scheduling problem. *European Journal of Operational Research*, 207(1), 1-14. https://doi.org/10.1016/j.ejor.2009.11.005

Hede, A. (2005). Sports-events, tourism and destination marketing strategies: an Australian case study of Athens 2004 and its media telecast. *Journal of Sport Tourism*, 10(3), 187-200. https://doi.org/10.1080/14775080500422452

Honggen, X. & Smith, S.L.J. (2003). Residents' perceptions of Kitchener-Waterloo Oktoberfest: an inductive analysis. *Event Management*, 8(3), 151-160. https://doi.org/10.3727/1525995031436917

Hu, Q., Zhang, Z., Baldacci, R., Tarantilis, C.D. & Zachariadis, E. (2023). The bus sightseeing problem. *International Transactions in Operational Research*. (in press). https://doi.org/10.1111/itor.13160

Jago, L., Chalip, L., Brown, G., Mules, T. & Shameem, A. (2003). Building events into destination branding: insights from experts. *Event Management*, 8(1), 3-14. https://doi.org/10.3727/152599503108751658

Karadakis, K., Kaplanidou, K. & Karlis, G. (2010). Event leveraging of mega sport events: a SWOT analysis approach. *International Journal of Event and Festival Management*, 1(3), 170-185. https://doi.org/10.1108/17852951011077998

Kendall, G., Knust, S., Ribeiro, C.C. & Urrutia, S. (2010). Scheduling in sports: an annotated bibliography. *Computers and Operations Research*, 37, 1-19. https://doi.org/10.1016/j.cor.2009.05.013

Kim, J., Kang, J. & Kim, Y.-K. (2014). Impact of mega sport events on destination image and country image. *Sport Marketing Quarterly*, 23(3), 161-175. (No DOI)

Kinnunen, M. & Haahti, A. (2015). Visitor discourses on experiences: reasons for festival success and failure. *International Journal of Event and Festival Management*, 6(3), 251-268. https://doi.org/10.1108/IJEFM-01-2015-0003

Li, X. & Vogelsong, H. (2005). Comparing methods of measuring image change: a case study of a small-scale community festival. *Tourism Analysis*, 10(4), 349-360. (No DOI)

Lin, C.-L., & Chang, K.-C. (2020). Establishing the service evaluation and selection system for emerging culture festival events using the hybrid MCDM technique. *Current Issues in Tourism*, 23(18), 2240-2272. https://doi.org/10.1080/13683500.2019.1665628

Liu, Z., Moon, I. & Zhang, R. (2023). Flexible vehicle scheduling with precedence constraints for tourists. *International Transactions in Operational Research*. (in press) https://doi.org/10.1111/itor.13256

Mackellar, J., & Nisbet, S. (2017). Sport events and integrated destination development. *Current Issues in Tourism*, 20(13), 1320-1335. https://doi.org/10.1080/13683500.2014.959903

Maeng, H.Y., Jang, H.Y. & Li, J.M. (2016). A critical review of the motivational factors for festival attendance based on meta-analysis. *Tourism Management Perspectives*, 17, 16-25. https://doi.org/10.1016/j.tmp.2015.10.003

Miao, L., Im, J., Fu, X., Kim, H. & Yi, E.Z. (2021). Proximal and distal post-COVID travel behavior. *Annals of Tourism Research*, 88, 103159. https://doi.org/10.1016/j.annals.2021.103159

O'Brien, D. (2006). Event business leveraging: the Sydney 2000 Olympic Games. *Annals of Tourism Research*, 33(1), 240-261. https://doi.org/10.1016/j.annals.2005.10.011

Özder, E.H., Özcan, E. & Eren, T. (2020). A Systematic Literature Review for Personnel Scheduling Problems. *International Journal of Information Technology and Decision Making*, 19(6), 1695-1735. https://doi.org/10.1142/S0219622020300050

Papies, D. & van Heerde, H.J. (2017). The Dynamic Interplay between Recorded Music and Live Concerts: The Role of Piracy, Unbundling, and Artist Characteristics. *Journal of Marketing*, 81(4), 67-87. https://doi.org/10.1509/jm.14.0473

Pappas, N. (2014). Hosting mega events: Londoners' support of the 2012 Olympics. *Journal of Hospitality and Tourism Management*, 21, 10-17. https://doi.org/10.1016/j.jhtm.2014.02.001

Patterson, I. & Getz, D. (2013). At the nexus of leisure and event studies. *Event Management*, 17(3), 227-240. https://doi.org/10.3727/152599513X13708863377836

Phi, G., Dredge, D. & Whitford, M. (2014). Understanding conflicting perspectives in event planning and management using Q method. *Tourism Management*, 40, 406-415. https://doi.org/10.1016/j.tourman.2013.07.012

Picard, D. & Robinson, M. (2006). Remaking worlds: festivals, tourism and change. In: D. Picard & M. Robinson (eds.), *Festivals, tourism and social change: Remaking worlds*. Clevedon: Chanel View Publications. ISBN 978-1845410476.

Polo-Mejía, O., Artigues, C., Lopez, P., Mönch, L. & Basini, V. (2023). Heuristic and metaheuristic methods for the multi-skill project scheduling problem with partial preemption. *International Transactions in Operational Research*, 30, 858-891. https://doi.org/10.1111/itor.13063

PwC (2021). *Global Entertainment & Media Outlook 2021–2025*, PricewaterhouseCoopers, LLP. Link: https://www.pwc.com/gx/en/entertainment-media/outlook-2021/perspectives-2021-2025.pdf (retrived 22/jul/2021)

Ribeiro, C.C. (2013). Sports scheduling: Problems and applications. *International Transactions in Operational Research*, 19, 201-226. https://doi.org/10.1111/j.1475-3995.2011.00819.x

Ribeiro, C.C. & Urrutia, S. (2007). Heuristics for the mirrored traveling tournament problem. *European Journal of Operational Research*, 179, 775-787. https://doi.org/10.1016/j.ejor.2005.03.061

Richter, F. (2019). The Largest Music Festivals in the World. In: *Statista.com* website. Link: https://www.statista.com/chart/17757/total-attendance-of-music-festivals/ (retrieved 23/jul/2021)

Ritchie, J.R.B. (2000). Turning 16 days into 16 years through Olympic legacies. *Event Management*, 6(2), 155-165. https://doi.org/10.3727/096020197390239

Saleh, F. & Ryan, C. (1993). Jazz and knitwear: Factors that attract tourists to festivals. *Tourism Management*, 14(4), 289-297. https://doi.org/10.1016/0261-5177(93)90063-Q

Schwindt, C. & Zimmermann, J. (Eds.) (2015). *Handbook on Project Management and Scheduling, Vols. 1 & 2*. Springer. ISBN 978-3319054438 (Vol.1, eBook), ISBN 978-3319059150 (Vol.2, eBook).

Serrato, M.A., Tello, J., Díaz, A., García, S. & Castillo, J.C. (2010). Visitor profile, satisfaction levels and clustering of tourists for decision making in Michoacan, Mexico. *International Transactions in Operational Research*, 17, 119-143. https://doi.org/10.1111/j.1475-3995.2009.00690.x

Smith, M. (2005). Spotlight events, media relations, and place promotion: a case study. *Journal of Hospitality and Leisure Marketing*, 12(1/2), 115-134. https://doi.org/10.1300/J150v12n01_08

Stewart, T.J. (1999). Concepts of Interactive Programming. In: Gal, T., Stewart, T.J., Hanne, T. (eds) *Multicriteria Decision Making*. International Series in Operations Research & Management Science, vol 21. Springer, Boston, MA. https://doi.org/10.1007/978-1-4615-5025-9_10

Stokes, R. (2006). Network-based strategy making for events tourism. *European Journal of Marketing*, 40(5/6), 682-695. https://doi.org/10.1108/03090560610657895

Stokes, R. (2008). Tourism strategy making: Insights to the events tourism domain. *Tourism Management*, 29, 252-262. https://doi.org/10.1016/j.tourman.2007.03.014

Tamiz, M. & Jones, D.F. (1997). An Example of Good Modelling Practice in Goal Programming: Means for Overcoming Incommensurability. In: Caballero, R., Ruiz, F. & Steuer, R. (eds) *Advances in Multiple Objective and Goal Programming*. Lecture Notes in Economics and Mathematical Systems, vol. 455. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-46854-4_3

Tan, K.-L., Sim, A.K.S., Chai, D. & Beck, L. (2020). Participant well-being and local festivals: the case of the Miri country music festival, Malaysia. *International Journal of Event and Festival Management*, 11(4), 433-451. https://doi.org/10.1108/IJEFM-02-2020-0007

Taneja, G. & Bala, A. (2022). Impact of online ratings on the box office collection of Bollywood movies. *International Journal of Internet Marketing and Advertising*, 17 (1/2). https://doi.org/10.1504/IJIMA.2022.125154

Tanford, S. & Jung, S. (2017). Festival attributes and perceptions: A meta-analysis of relationships with satisfaction and loyalty. *Tourism Management*, 61, 209-220. https://doi.org/10.1016/j.tourman.2017.02.005

Taplin, J.H.E. & McGinley, C. (2000). A linear program to model daily car touring choices. *Annals of Tourism Research*, 27(2), 451-467. https://doi.org/10.1016/S0160-7383(99)00086-9

Tkaczynski, A. (2013). A stakeholder approach to attendee segmentation: a case study of an Australian Christian music festival. *Event Management*, 17, 283-298. https://doi.org/10.1080/15022250.2014.946231

Van den Bergh, J., Beliën, J., De Bruecker, P., Demeulemeester, E. & De Boeck, L. (2013). Personnel scheduling: A literature review. *European Journal of Operational Research*, 226(3), 367-385, https://doi.org/10.1016/j.ejor.2012.11.029

Van Heerden, C. & Saayman, M. (2018). Sustainability of a national arts festival: An application of a data envelopment analysis approach. *Tourism Economics*, 24(5), 576-592. https://doi.org/10.1177/1354816618762186

Weber, K. & Hsu, C.H.C. (2021). Banding together in a festival context: Examining effects of a joint-stakeholder external service recovery. *Tourism Management*, 83, 104204. https://doi.org/10.1016/j.tourman.2020.104204

Weed, M. & Bull, C. (2009). *In Sports tourism: Participants, policy and providers, 2nd edition*. Oxford: Elsevier. ISBN 978-0080942117 (eBook)

Yan, G., Kloeppel, M. & Li, X. (R.) (2017). Producing Extreme Metal festivals: An analysis from Lacan's gaze. *Tourism Management*, 59, 579-589. https://doi.org/10.1016/j.tourman.2016.09.014

Yolal, M., Gursoy. D., Uysal, M., Kim, H.(L.) & Karacaoğlu, S. (2016). Impacts of festivals and events on residents' well-being. *Annals of Tourism Research*, 61, 1-18. https://doi.org/10.1016/j.annals.2016.07.008

Zhang, Z., Zhu, L., Chen, Y. and Guan, C. (2023), A multi-objective hybrid evolutionary search algorithm for parallel production line balancing problem including disassembly and assembly tasks. *International Transactions in Operational Research*, 30, 3508-3553. https://doi.org/10.1111/itor.13220

Zeleny, M. (1982) *Multiple Criteria Decision Making.* McGraw-Hill, New York.

Zheng, W. & Liao, Z. (2019). Using a heuristic approach to design personalized tour routes for heterogeneous tourist groups. *Tourism Management*, 72, 313-325. https://doi.org/10.1016/j.tourman.2018.12.013

Zheng, W., Ji, H., Lin, C., Wang, W. & Yu B. (2020). Using a heuristic approach to design personalized urban tourism itineraries with hotel selection. *Tourism Management*, 76, 103956. https://doi.org/10.1016/j.tourman.2019.103956

Zhong, L., Sun, S., Law, R. & Li, X. (2021). Tourism crisis management: evidence from COVID-*19. Current Issues in Tourism* (in press). https://doi.org/10.1080/13683500.2021.1901866

Ziakas, V. & Getz, D. (2021). Event portfolio management: An emerging transdisciplinary field of theory and praxis. *Tourism Management*, 83, 104233, https://doi.org/10.1016/j.tourman.2020.104233

Zografos, C. & Oglethorpe, D. (2004). Multi-Criteria Analysis in Ecotourism: Using Goal Programming to Explore Sustainable Solutions. *Current Issues in Tourism*, 7(1), 20-43. https://doi.org/10.1080/13683500408667971

Appendix A

A possible festival flyer

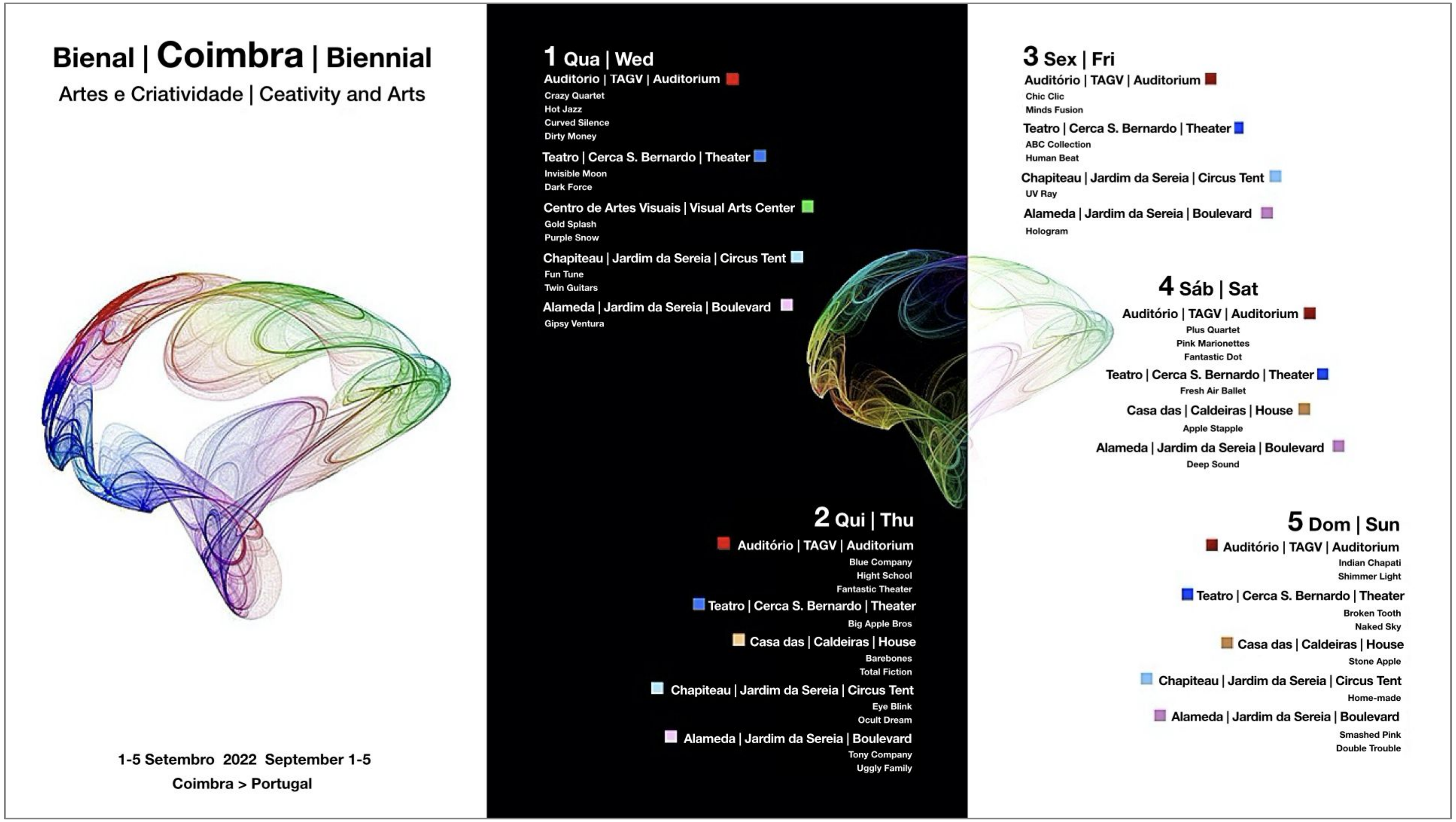


Figure A1. Festival Flyer based on the Goal L_∞ solution

Appendix B

Further exploration of solution space and trade-off analysis

A total of 235 extra solutions to the case study were generated, spanning combinations of weights having ternary values of 1, 2 and 3, with subsequent normalization s.t. $\sum_i w_i = 1$, and removal of duplicate weights, for a total of 235 additional solutions. In the supplemental material to this article the reader can find a spreadsheet containing solution profiles for all 248 solutions derived, ordered by cost (O1) values.

For these 248 solutions, specific renown scores, i.e., the quotient between renown (O2) and number of lined up activities, averaged 0.411 with little dispersion (standard deviation 0.0068), proving the model succeeds in selecting the most impactful activities, as the average of the product $W_c^C W_{ac}^A$ was 0.388. Looking at the solutions in increasing order of cost, it was possible to see that, as expected, within each category the number of lined up activities grows from N_c^{mC} to N_c^{MC} as budget increases. This was the case for most categories, but three (non-mandatory, $N_c^{mC} = 0$) categories in particular exhibited a very small number of appearances in the 248 solutions, namely once, seven, and 25 times. This was already noticed while exploring Tables 7 and 8 in the manuscript text and can be tracked down to low on renown and the corresponding activities being too expensive.

A similar analysis, now at the level of each activity, reveals that the total number of lined up activities ($\sum x_{acsd}$) ranged from 33 to 47 for the whole festival. Out of the 100 activities, 20 were lined up at least once in all of the 248 solutions. Of these 20, eight were so by a $N_{ac}^{mA} = 1$ parameter, which forces their lineup. The remaining were naturally selected by model solving. A total of 40 activities featured in at least half the solutions, so the case study data points at these activities as the most efficient ones and natural candidates for advanced booking of the corresponding artists. On the other hand, 55 activities feature in at most 25 of the 248 solutions. These activities are not very competitive in terms of their contribution to the model objectives and therefore only get selected under special circumstances, confirming the trend from Tables 7 and 8.

It is important to note that the reason why some activities always get lined up, while others never get lined up, essentially has to do with the specifics of case study data and parameter choice. Other datasets and parameters may lead to different scenarios when it comes to how often an activity features in the solutions.

Plotting the 248 solutions as a function of cost reveals the behavior of the model in general. In Figures B1 to B4 below 2D plots of O*x* vs. cost (O1) are presented. In those figures, Opt*x* solutions are presented in red, FocusO*x* solutions in orange and goal programming solutions in green. Blue solutions are weighted sum solutions.

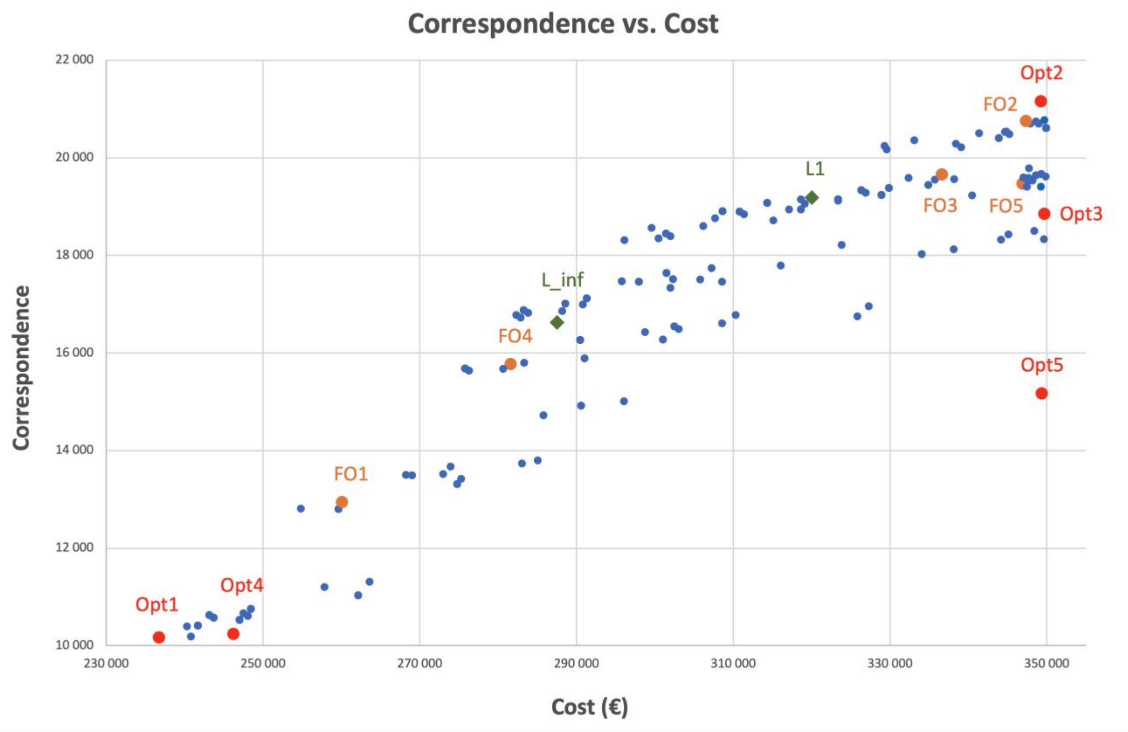


Figure B1. Correspondence vs. Cost for 248 solutions (O2 vs. O1 plot).

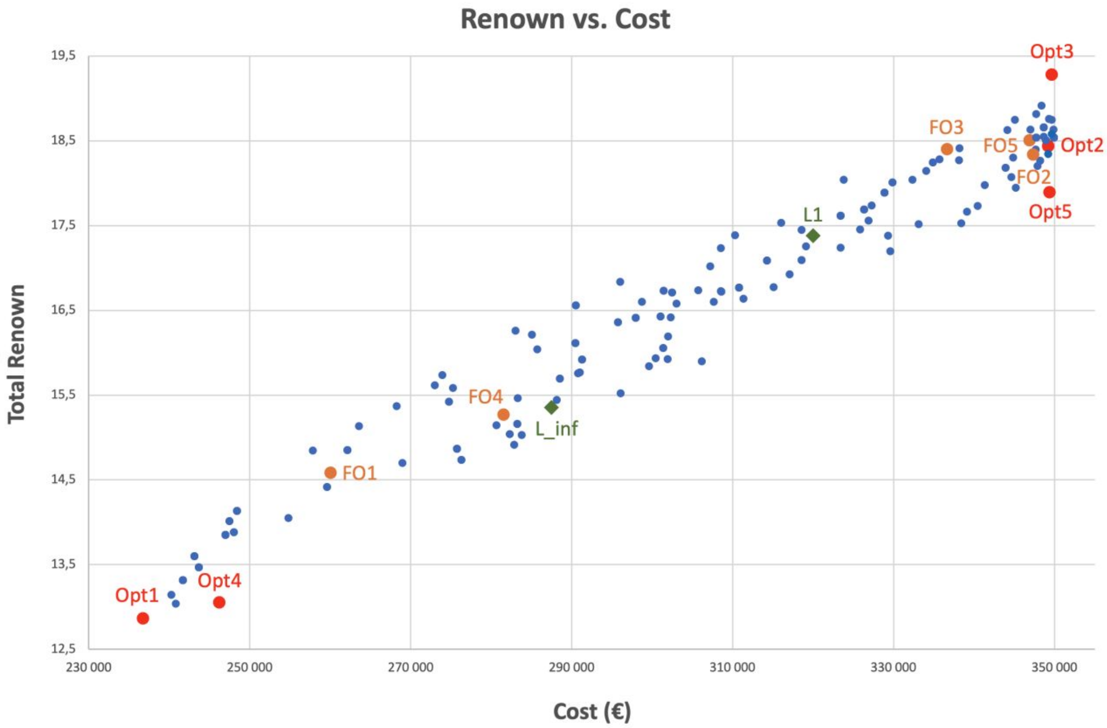


Figure B2. Renown vs. Cost for 248 solutions (O3 vs. O1 plot).

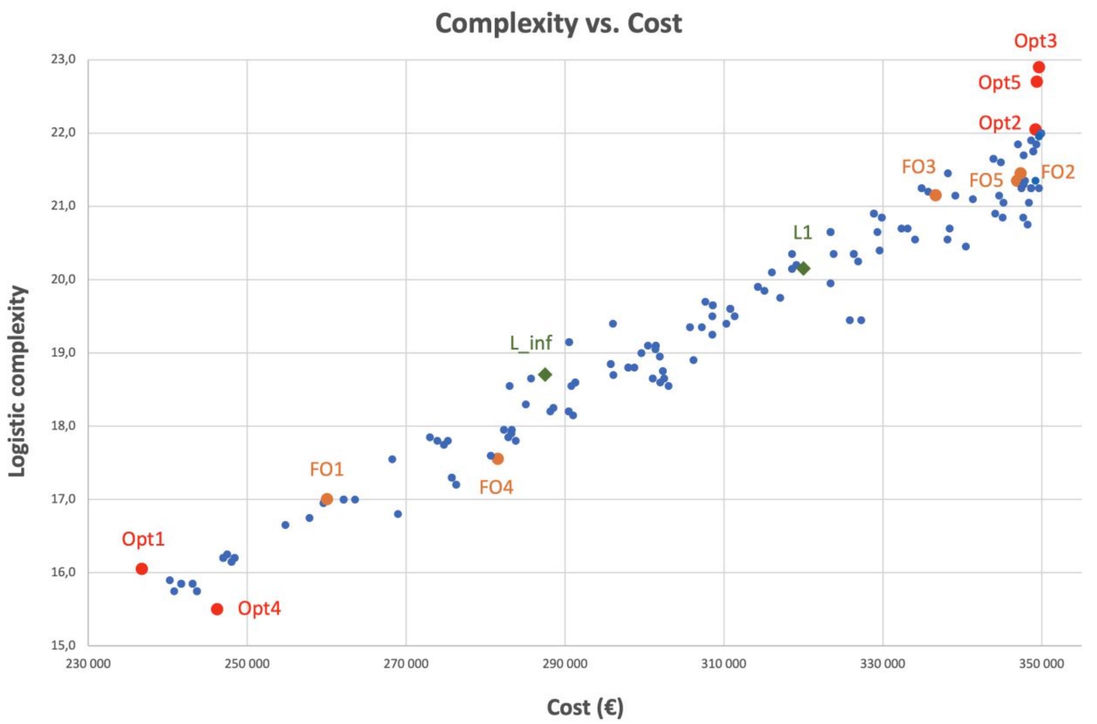


Figure B3. Logistic complexity vs. Cost for 248 solutions (O4 vs. O1 plot).

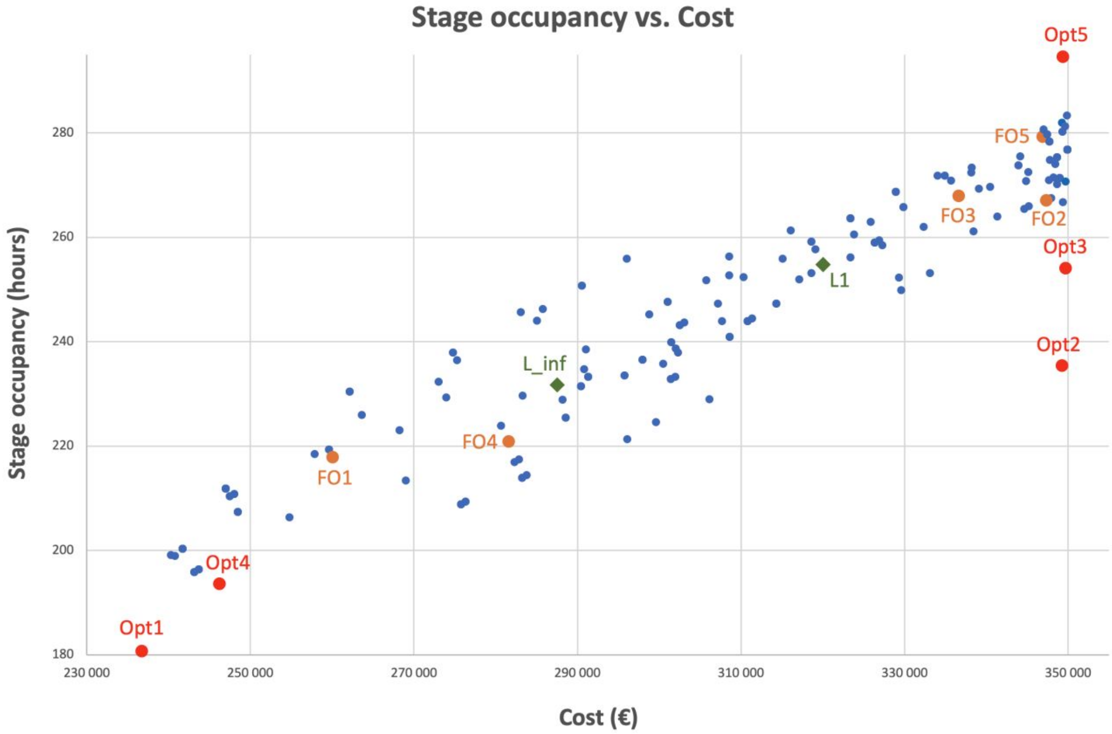


Figure B4. Stage occupancy vs. Cost for 248 solutions (O5 vs. O1 plot).

Similar figures could be derived for general Ox_i vs Ox_j. Figures B1-B4 show a trend of increasing objective value (y-axis) as investment cost increases (x-axis). The increase is relatively linear for correspondence and renown (Figs. B2 and B3), but wider and more scattered for stage occupancy (Figs. B1 and B4), but this is due to the circumstantial factor of case study data. All plots show that the Opt$x$ solutions are indeed extreme and therefore unlikely to be selected as a basis for implementation.

A more interesting analysis is that of distance to the ideal solution vs. cost. This is featured in Figures B5 and B6 below.

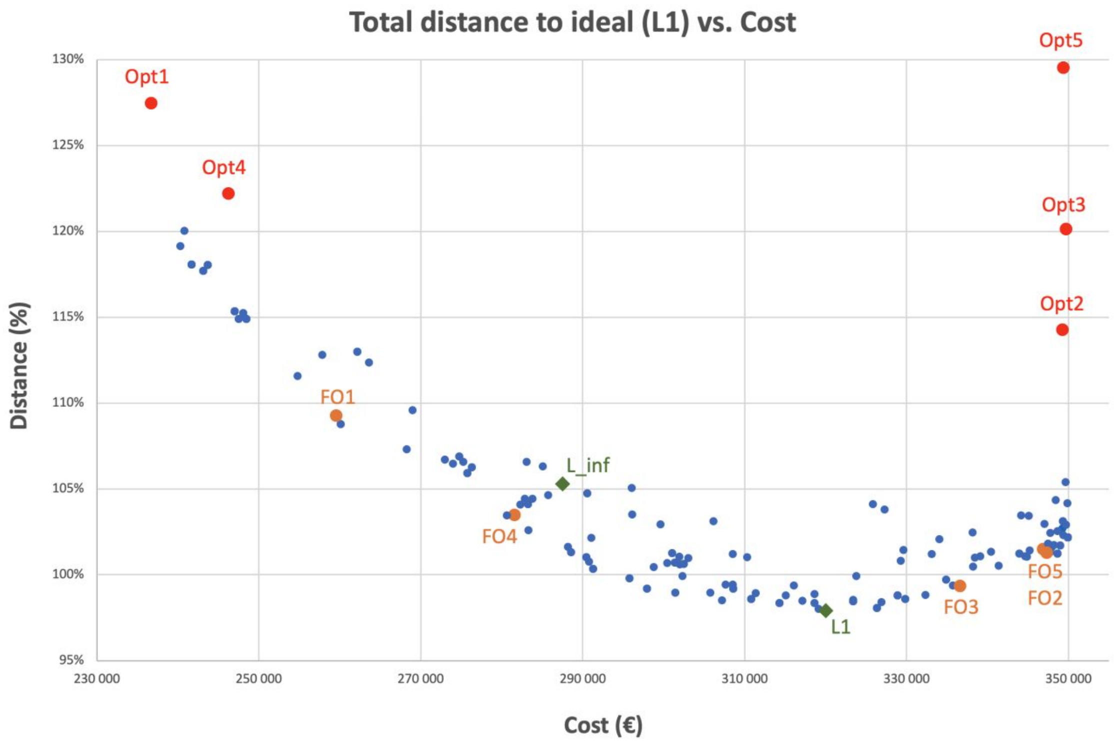


Figure B5. L_1 distance to ideal vs. Cost for 248 solutions.

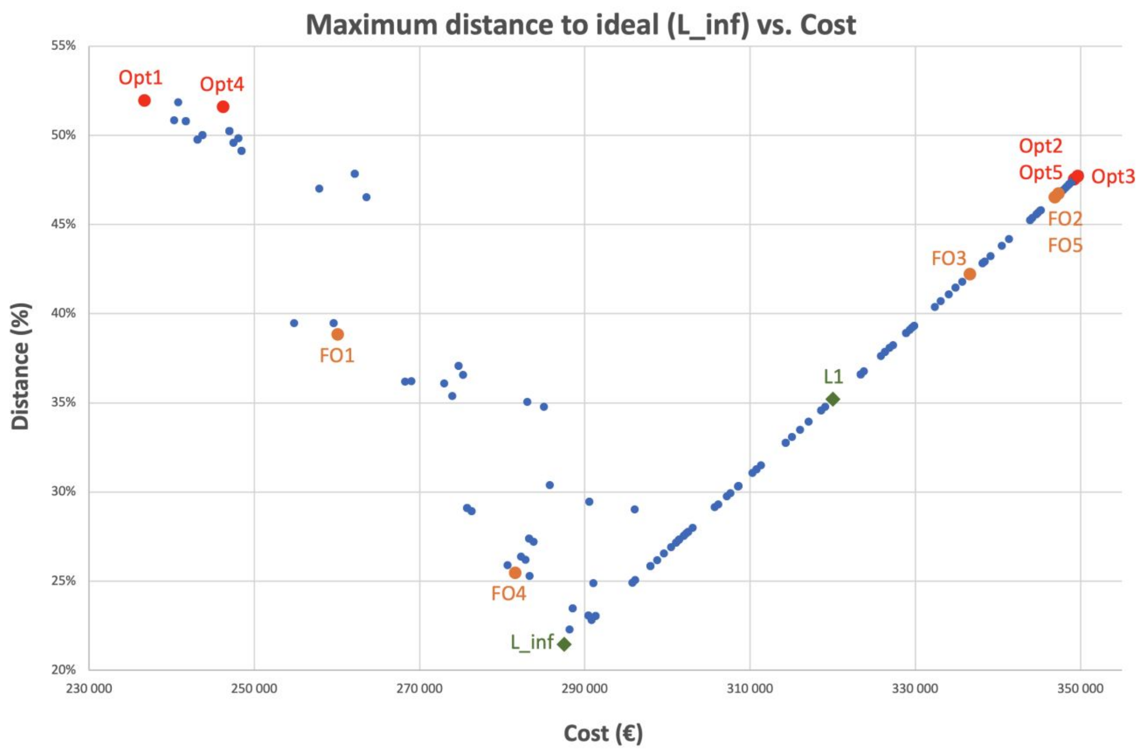


Figure B6. L_∞ distance to ideal vs. Cost for 248 solutions.

Figures B5 and B6 show that solution distance to the ideal improves with more spending, up to the point where the L_p minimum is reached, and more investment increases becomes penalizing, despite improving renown, correspondence, and stage occupancy, due to added costs and complexity. The linear increase in Fig. B6 is curious and can be explained considering that L_∞ measures the maximum distance to the ideal. As the budget allowance increases, cost becomes the objective with the most distance to the ideal and this is precisely what the vertical axis show: for high budget, doubling the cost means doubling the distance to the ideal and a linear plot emerges.

Looking at all Figures B1 to B6, it is noted that FocusOx and goal programming solutions seem to cover a good extent of the Pareto front. However, since no FocusOx solution sits close to L_1, which is equivalent to the equal weights solution, this latter combination of weights is important to consider.

Solution selection from a wider set

When many solutions are generated, an interesting management feature of the model is it can be used to select solutions on the fly. That is to say, by looking at the detailed breakdown of the 248 solutions, e.g., in the format of the spreadsheet in the supplemental material, the decision maker can contact the artists asking for their availability, and successively remove solutions from the pool as artists eventually decline the invitation. This will work best for artists which would feature in a lot of solutions and/or play key roles in the festival (e.g., star activities), as such declinations quickly narrow down the pool of solutions, making it easier to select the final lineup. An advantage of this methodology is that it may not be necessary to rerun model calculations, should an artist decline an invitation to participate. Likewise, activities which never get selected can be quickly discarded.