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Optimization of Olympic Game-Watching Schedules: A Socioeconomic Analysis for Paris 2024

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ABSTRACT

The Olympic Games have evolved into a global event showcasing athletic and cultural excellence. However, economic challenges restrict accessibility for many spectators, particularly those from less affluent regions. This study introduces a graph theory-based integer optimization model to improve Olympic event-watching schedules, aiming to maximize spectator experiences while addressing logistical and economic constraints. The computational experiments, including a global income analysis and a detailed case study of Brazilian spectators at the Paris 2024 Olympics, have revealed significant disparities in event attendance across income classes and continents. The results highlight the financial barriers faced by lower-income groups and emphasize the need for policies promoting greater accessibility. Consequently, the proposed optimization model offers potential benefits for event organizers in logistical planning and enhancing spectator satisfaction.

KEYWORDS. Paris 2024 Olympic Games. Socioeconomic Analysis. Integer Programming.
Paper topics (OA – Other Aplications in OR; OC – Combinatorial Optimization)

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1. Introduction

The Olympic Games, with a history that traces back to ancient Greece, have long been a pinnacle of athletic and cultural achievement. Originally held every four years in Olympia, these games were as much a religious festival in honor of Zeus as they were an athletic competition, featuring events like running, wrestling, boxing, and chariot racing, accompanied by cultural performances and ritual sacrifices [Young, 2004]. Since their revival in 1896, the modern Olympics have transformed into a global phenomenon, attracting professional athletes from over 200 nations and promoting values such as sportsmanship and international cooperation [Jorge, 2022; Wlodarczyk and Rozmiarek, 2022].

Today, the Games not only serve as a platform for elite sports competition but also act as a significant catalyst for urban development, educational initiatives, and cultural exchange in the host cities. These developments foster a spirit of global unity and the pursuit of excellence, amidst the festivity [Telles and Machado, 2022]. Despite their success, the Games face ongoing challenges related to accessibility, equity, and the impacts of commercialization, which sometimes overshadow their unifying goals [Shvetsova and Fomin, 2022].

Economic challenges also loom large, as the soaring costs associated with hosting the Games can be prohibitive, especially for less affluent nations [Preuss and Weitzmann, 2023; Li, 2023]. These financial constraints extend to spectators, many of whom can only afford to attend a few events, despite a broader desire to fully experience the Olympics [Sakaki et al., 2022]. Recognizing these barriers, organizers have expanded digital and streaming options, allowing for broader access through platforms like Peacock, Hulu, and YouTube TV. Yet, the costs of subscriptions and pay-per-view content continue to pose barriers, underscoring the delicate balance between offering a spectacle and ensuring global accessibility [Tomlinson, 2022; Horne, 2022].

Mathematical models and techniques have proven invaluable in this regard, as demonstrated by various studies that address scheduling and resource optimization for sports events. These methodologies transform complex logistical challenges into structured optimization problems, capable of enhancing the experience for all stakeholders athletes, spectators, and hosts alike [Jiang et al., 2007; Xie, 2013; Singh, 2017; Sagir et al., 2019].

In this work, we propose a novel approach to optimize the Olympic event-watching schedule by employing a graph-based modeling. This methodology not only aims to maximize the individual spectator experience through personalized scheduling but also addresses broader issues of accessibility and economic efficiency.

The remainder of the paper is organized as follows: Section 2 provides a detailed problem definition, including the mathematical formulation of our model. Section 3 describes the computational experiments conducted and presents the results, including a case study for the Paris 2024 Olympic Games and a socioeconomic discussion. Finally, Section 4 concludes the paper and outlines potential directions for future research.

2. Problem Definition

This section addresses the logistical challenge of optimizing Olympic Game-Watching Schedules. Given the multitude of events distributed across different venues and times, creating an optimal viewing schedule is inherently complex. This study formulates this as a network flow optimization problem, aiming to develop personalized viewing schedules that maximize preference scores while ensuring travel and schedule feasibility.

Consider a directed graph $G = (V, A)$, where V is the set of vertices representing the Olympic events, and A is the set of arcs representing transitions between events.

Each event $i \in V$ is defined by its start time t_i^{start} and end time t_i^{end}, where $t_i^{\text{end}} = t_i^{\text{start}} + \text{duration}_i$ where duration_i represents the length of the event in minutes. Here, t_i^{start} is the minute within the total timeline of the Olympics when event i begins.

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Each event has an associated ticket price c_i. Additionally, there is an average travel cost per minute c_{ij} for the arc $(i, j) \in A$. The total travel cost between events i and j is given by $c_{ij} \times t_{ij}$, where t_{ij} is the travel time in minutes between the two events. Spectators have a total budget B, which is a upper limit on the total costs that must cover both the ticket prices and the travel costs.

In addition to costs, each event $i \in V$ has a preference score p_i that reflects the level of interest spectators have in attending the event.

Let x_{ij} be a binary decision variable for the arc $(i, j) \in A$, where $x_{ij} = 1$ if a spectator travels from event i to event j, and $x_{ij} = 0$ otherwise. Similarly, let w_i be a binary decision variable for the vertex $i \in V$, where $w_i = 1$ if a spectator attends event i, and $w_i = 0$ otherwise.

The optimization problem is formulated as follows:

$$\text{Maximize} \quad Z = \sum_{i \in V} p_i w_i \tag{1}$$

$$\text{subject to} \tag{2}$$

$$\sum_{j \in V \setminus \{i\}} x_{ij} = w_i, \quad \forall i \in V \setminus \{n+1\} \tag{3}$$

$$\sum_{i \in V \setminus \{j\}} x_{ij} = w_j, \quad \forall j \in V \setminus \{0\} \tag{4}$$

$$\sum_{i \in V} x_{0i} = 1 \tag{5}$$

$$\sum_{i \in V} x_{i(n+1)} = 1 \tag{6}$$

$$t_i^{\text{end}} + t_{ij} - M_{ij}(1 - x_{ij}) \leq t_j^{\text{start}}, \quad \forall i, j \in V, i \neq j \tag{7}$$

$$\sum_{i \in V} c_i w_i + \sum_{j \in V} x_{ij} c_{ij} t_{ij} \leq B \tag{8}$$

$$x_{ij} \in \{0, 1\}, \quad \forall (i, j) \in A \tag{9}$$

$$w_i \in \{0, 1\}, \quad \forall i \in V \tag{10}$$

where,

$$M_{ij} = \max\{0, t_i^{\text{end}} + t_{ij} - t_j^{\text{start}}\} \tag{11}$$

The objective function (1) aims to maximize the total preference score, enhancing the overall event experience by prioritizing high-preference events. Sequence Constraints (3) and (4) ensure logical transitions between attended events. Constraints (5) and (6) ensure the initiation and termination of the flow. The family of Contraints (7) ensures feasible transitions between events, allowing travel from event i to event j only if there is enough time between the end of event i and the start of event j, given by the travel time t_{ij}. The Budget Constraint (8) limits the total expenditure on event tickets and travel costs. Finally, constraints (9) and (10) ensure that the decision variables x_{ij} and w_i are binary.

3. Methodology

This section outlines the methodology introduced in this study to optimize the viewing schedule for spectators at the Olympic Games. The approach consists of three main components: data collection, model implementation, and analysis of results.

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3.1. Data Collection

The primary data for this study was sourced from the official releases of the Paris Olympic Committee[1], which included comprehensive information on event schedules, ticket prices, and venue locations. Specifically, we collected detailed start and end times for all Olympic events, the costs associated with attending each event, and the geographic coordinates and addresses of all event venues.

To gather this data, we developed algorithms that extracted information directly from the official Olympics website. This process was particularly challenging due to the difficulty in accessing and organizing the information, which is not readily available or easy to manipulate. Such complexities underline the challenge of applying this methodology to past Olympics, where data availability is even more restricted. Extensive data cleaning and organization were required to ensure the accuracy and usability of the dataset.

3.2. Model Implementation

The key steps in the model implementation include constructing a directed graph, calculating travel times, and assigning preference scores and costs.

Each event was assigned a preference score based on spectator interest, which the spectators themselves rated across five categories: Very Uninterested, Slightly Interested, Neutral, Interested, and Very Interested. These categories were weighted numerically in the model, with values ranging from 1 to 5, where 'Very Uninterested' corresponds to the lowest weight (1) and 'Very Interested' to the highest weight (5). Additionally, the associated prices for tickets were included to reflect the financial aspect of attending the events.

For on-site spectators, travel times between venues were calculated using Geographic Information System (GIS) tools, considering real-world travel routes and times by car to ensure feasible transitions between events within the given schedule.

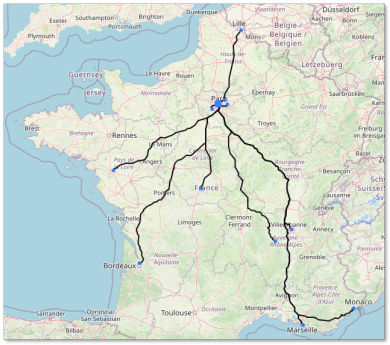


Figure 1: Optimal Routes By Car for On-site Spectators

Travel costs were incorporated into the model by estimating the average travel cost per minute in Paris, considering multiple transportation modes, each with distinct cost structures. According to the Regie Autonome des Transports Parisiens (RATP), the cost of a single metro or bus ticket is approximately €1.90, with an average trip duration of 30 minutes, translating to a cost of €0.063 per minute [Backpacker, 2024]. Taxi fares in Paris vary by time of day, with a day tariff of €0.53 per minute and a night tariff of €0.60 per minute [BetterTaxi, 2024]. For Uber services, the cost is €0.30 per minute [Guide, 2024].

[1] https://tickets.paris2024.org/en/

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To integrate these different transportation modes into a single average travel cost per minute, a weighted average approach was used. The average cost per minute was calculated as follows:

$$\text{Average cost per minute} = \frac{0.063 + 0.53 + 0.30}{3} \approx 0.298 \tag{12}$$

Using this average travel cost, a budget constraint was included in the optimization model to ensure that the total cost, encompassing both event costs and travel costs, did not exceed the allocated budget. The travel cost component was computed by multiplying the travel time between events by the average cost per minute.

3.3. Analysis

The results of the computational experiments were analyzed to derive insights into the effectiveness of the proposed model. The analysis was divided into two main parts: a global analysis and a specific case study for Brazilian spectators.

For the global analysis, we investigated the impact of income disparities on Olympic attendance by analyzing median incomes across continents using data from the World Bank[2]. The steps included gathering median income data, converting annual median income to monthly values, and using these as budget limits in the optimization model to determine the maximum number of events affordable for individuals from each continent.

In the case study for Brazilian spectators, different income classes were analyzed using data from the Pesquisa de Orçamentos Familiares (POF) IBGE 2017-2018[3]. Social classes were defined based on the IBGE classification and the 2024 minimum wage. Budget limits were established for each class, and the optimization model was employed to determine the maximum number of events each class could afford. Furthermore, the number of months required to save for various levels of engagement with the Olympic Games was calculated, taking into account the average cost of a ticket and the proportion of income allocated to "Recreation & Culture" in order to afford different attendance profiles for events.

These calculations do not include travel expenses to Paris. The additional financial burden of these expenses would further limit the number of events that individuals from lower-income regions could afford to attend.

4. Computational Experiments and Results

This section presents the computational experiments conducted and their corresponding results. The experiments were carried out on a machine equipped with an AMD Ryzen 9 7900X AM5 processor, operating at 5.6 GHz, and 32GB of DDR5 RAM. The proposed method was implemented using Python, specifically leveraging the SciPY[4] mathematical solver within a Python 3.10 framework. Each instance was tested ten times to ensure the robustness and reliability of the results.

4.1. Global Analysis: Income Levels and Olympic Attendance

The ability of individuals to attend global events like the Olympic Games is significantly influenced by the disparity in median incomes across different continents. This subsection provides a detailed analysis of the global income levels and their impact on Olympic attendance. For the purposes of these analyses, preferences were set to be neutral for all options, allowing for an unbiased evaluation of the method's performance.

[2] https://www.worldbank.org/en/home
[3] https://www.ibge.gov.br
[4] https://scipy.org/

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4.1.1. Results

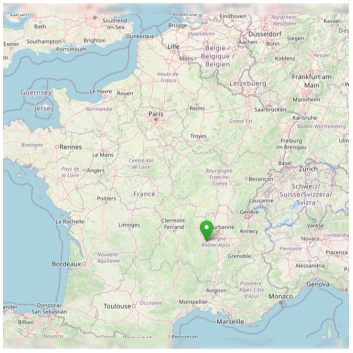
The Table 1 presents the average median monthly income by continent, highlighting the significant disparities that influence individuals' ability to participate in the Olympic Games. It also summarizes the results, showing the maximum number of events and the total amount spent by spectators from different continents.

Table 1: Average Monthly Median Income and Summary of Events by Continent (Source: World Bank)

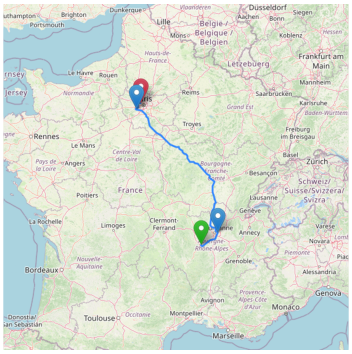
Continent	Income (€)	Max Events	Time (s)	Costs (€)		
				Ticket	Travel	Total
Africa	137.54	5	60.2	120	0	120
Asia	683.77	15	35.4	533	117.6	650.6
Europe	1,969.28	30	16.7	1609	294.6	1903.6
North America	924.64	18	15.4	739	150.2	889.2
Oceania	845.98	17	19.9	669	167.9	836.9
South America	465.33	12	18.9	375	19.25	394.2

The Figure 2 shows the optimal routes for attending events by continent, given as a result.

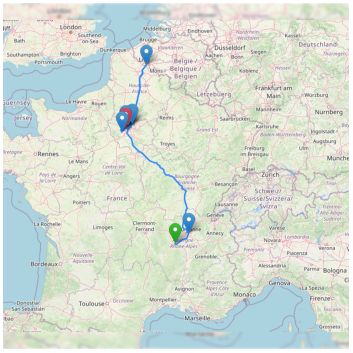
Figure 2: Routes by Continent



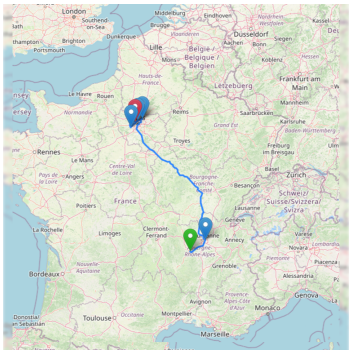
(a) Africa



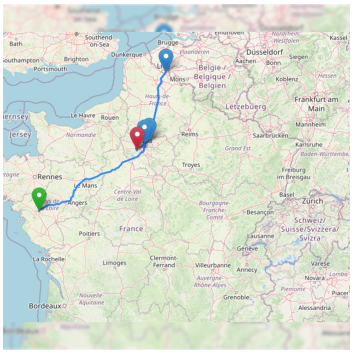
(b) Asia



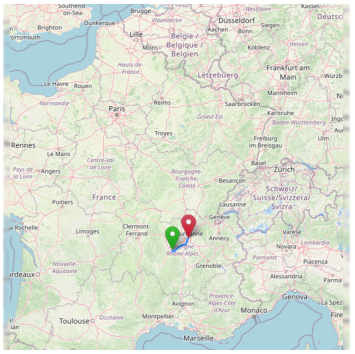
(c) Europe



(d) North America



(e) Oceania



(f) South America

Individuals from Africa, with a median income of approximately €137,54 per month, can only afford to attend a maximum of five events, assuming an average ticket price of €26,40. In

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contrast, individuals from Europe, with a median income of €1.969,28 per month, can afford to attend up to 40 events. This significant difference in affordability underscores how higher median incomes facilitate greater access to cultural and sporting events, fostering a more inclusive and diverse audience.

When broadening our analysis, significant differences in the profiles of Olympic attendance across various regions become evident. This reality is particularly pronounced when examining specific national contexts. Such an examination allows us to demonstrate that economic disparities significantly impact the feasibility of attending the Olympic Games, even within a single country.

4.2. Brazil: Income Levels and Olympic Attendance

This analysis explores the economic feasibility for different Brazilian income classes to participate as spectators in the Olympic Games. It aims to understand the inclusivity of such global events and identify potential barriers for lower-income groups within the same country.

4.2.1. Results

We begin by analyzing the distribution of per capita family income across different classes in Brazil, as presented in 2.

Table 2: Data from POF IBGE 2017-2018

Per Capita Family Monthly Income Classes (R$)	People		Per Capita Family Income (R$)	% of Total Income in Class
	Number (thousand)	(%)		
From 0 to 400	29,796	14.39	257.54	2.05
More than 400 to 700	35,484	17.13	546.79	5.18
More than 700 to 1,000	31,632	15.27	842.56	7.12
More than 1,000 to 1,300	25,402	12.27	1,145.71	7.77
More than 1,300 to 1,600	18,818	9.09	1,442.44	7.25
More than 1,600 to 2,000	16,971	8.19	1,784.78	8.09
More than 2,000 to 3,000	21,353	10.31	2,418.12	13.79
More than 3,000 to 5,000	15,268	7.37	3,777.09	15.40
More than 5,000 to 10,000	8,694	4.20	6,872.73	15.95
More than 10,000	3,686	1.78	17,692.01	17.41

Using the IBGE classification and the 2024 minimum wage of R$ 1,412, the social classes in Brazil are defined as shown in Table 3, with the equivalent amounts in euros also provided.

Table 3: Proportion of people in each social class based on income distribution (in euros)

Social Class	Proportion of People (%)	Value (€)
Class A	1.78	3,283.09
Class B	4.20	1,275.86
Class C	17.68	700.43
Class D	29.55	330.99
Class E	46.79	101.37

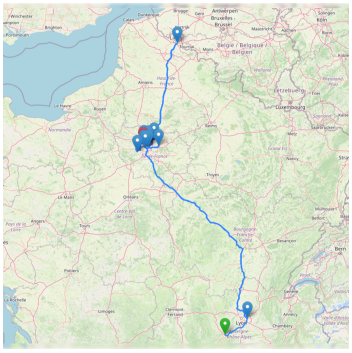
A detailed summary of the optimization model results, including the maximum number of events attended, total expenditure, and execution time for spectators across different income classes, is provided in Table 4

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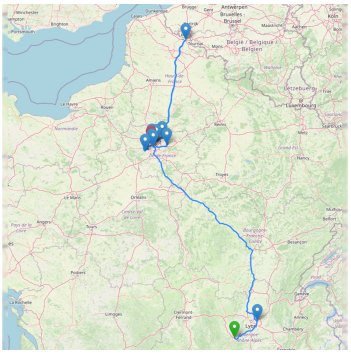
Table 4: Summary of Events, Total Spent, and Execution Time by Income Classes

Class	Income (€)	Max Events	Time (s)	Costs (€)		
				Ticket	Travel	Total
A	6,248.00	36	16.3	5171	583.9	5754.9
B	3,124.00	35	15.4	2310	317.5	2627.5
C	1,249.60	23	15.6	1014	221.4	1235.4
D	624.80	14	25.9	453	117.5	570.5
E	312.40	10	60.5	275	19.2	294.2

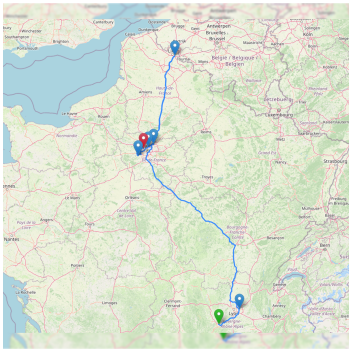
Figure 3: Routes by Class



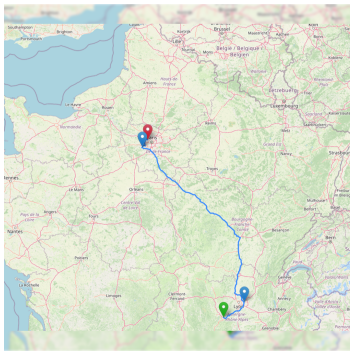
(a) Class A



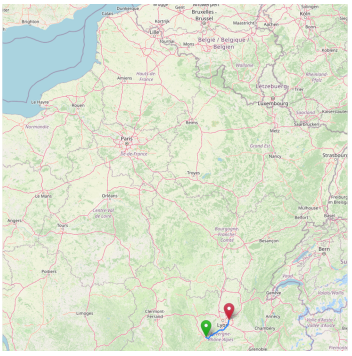
(b) Class B



(c) Class C



(d) Class D



(e) Class E

The results highlight significant disparities in event attendance and total spending across income classes:

- High-income Spectators (Class A): This group enjoys the most extensive access to events, indicating a clear advantage in terms of cultural and entertainment engagement.
- Middle-income Spectators (Classes B and C): These groups can attend a considerable number of events but with notable reductions in both the number of events and the diversity of events.
- Low-income Spectators (Classes D and E): The most disadvantaged groups, with the least number of events attended and the lowest diversity of events. The high execution time for

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Class E (60.5 seconds) suggests greater difficulty in optimizing their schedule within financial constraints.

The stark differences in attendance and spending underscore the barriers that low-income spectators face. These barriers include financial constraints, as the limited income of Classes D and E restricts their ability to attend a significant number of events, reflecting broader issues of economic inequality. Given that a significant portion of the Brazilian population falls within these categories (29.55% in Class D and 47.79% in Class E), the limited access to cultural and sporting events can exacerbate feelings of exclusion and reduce the overall inclusivity of the Olympics. This highlights the urgent need for policies that promote greater accessibility for all income groups.

It is important to note that the analysis assumes that all available monthly income would be allocated to event attendance. This assumption does not accurately reflect reality, as individuals have other essential expenses. Therefore, the spending figures should be interpreted as hypothetical, representing a scenario where each income class could allocate their entire available monthly budget specifically for events. This hypothetical framework is used to illustrate the disparities; however, it must be approached with caution, as actual spending behavior would likely reveal even more pronounced limitations for lower-income groups.

To further illustrate these disparities, we analyze the breakdown of income allocation and household expenditures in Brazil. This analysis delves into the specifics of how much each social class allocates from their salary income to various expenses and the time required for each class to save enough to afford different types of Olympic attendance profiles. According to POF data, the allocation of income for the average Brazilian family is distributed as shown in Table 5, which illustrates the percentage of income allocated to various expenditure categories.

Table 5: Income Allocation for the Average Brazilian Family

Category	Proportion (%)
Food	20.0
Housing	25.0
Transportation	15.0
Healthcare	10.0
Education	10.0
Recreation & Culture	2.6
Others	17.4

Notably, only 2.6% of the average Brazilian family's income is allocated to "Recreation & Culture," which is the relevant category for attending events such as the Olympic Games.

To evaluate the economic feasibility of attending the Olympic Games, we examined different levels of engagement based on the number of events attended. Engagement levels were defined as follows: Low Engagement corresponds to attending 3 to 5 events, Moderate Engagement to attending 6 to 10 events, Considerable Engagement to attending 11 to 20 events, and High Engagement to attending more than 20 events.

Assuming an average cost of attending the Olympic Games, we calculated the total cost and the corresponding number of months required for saving based on the proportion of income allocated to "Recreation & Culture." Table 6 summarizes the results for various income classes and levels of engagement.

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Table 6: Months Needed to Save for Various Levels of Olympic Engagement by Income Class

Class	Engagement Level	Number of Events	Months Needed to Save
A	Low	5	1
	Moderate	10	2
	Considerable	20	4
	High	25	5
B	Low	5	1
	Moderate	10	3
	Considerable	20	6
	High	25	8
C	Low	5	2
	Moderate	10	6
	Considerable	20	11
	High	25	16
D	Low	5	4
	Moderate	10	11
	Considerable	20	21
	High	25	35
E	Low	5	14
	Moderate	10	38
	Considerable	20	70
	High	25	117

This analysis reveals significant socioeconomic disparities in the feasibility of attending the Olympic Games among different Brazilian income classes. The majority of Brazilians fall into classes D and E, which face considerable financial barriers to participating in such global events. Given the high cost of Olympic tickets, even with maximum savings from their income allocated to "Recreation & Culture," attending multiple events remains a significant challenge for these classes. For instance:

- Class D: To attend 10 events (Moderate Engagement), a family would need to save for approximately 11 months. To reach the highest engagement level, attending more than 20 events, a family in this class would need to save for around 35 months.
- Class E: The situation is even more challenging, with families needing to save for around 38 months for moderate engagement and up to 117 months for high engagement. Given the Olympics occur every four years, this equates to over 9 years of savings for the highest engagement level, making it practically unattainable.

In addition to the ticket costs, travel expenses from Brazil to Paris add another layer of financial burden. The average cost of a round-trip flight from Brazil to Paris can range from R$ 3,000 to R$ 5,000, depending on the season and booking time. For a family, these costs multiply, making the overall expenditure even more prohibitive.

The analysis highlights the stark economic challenges faced by lower-income Brazilian families in attending the Olympic Games. While higher-income families in classes A and B can

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afford to engage in such events with relative ease, the majority of the population in classes D and E confront substantial financial barriers. This disparity calls for initiatives to improve the accessibility of global events, such as subsidized tickets, travel grants, and community support programs.

5. Conclusion

This paper presents a optimization model designed to optimize Olympic game-watching schedules, demonstrated through a case study of the Paris 2024 Olympic Games. The model efficiently integrates event data with individual spectator profiles, considering budget constraints and specific interests, to maximize viewer experience.

Our computational experiments reveal significant disparities in the ability of individuals from different continents to attend the Olympic Games, driven by varying median incomes. For example, individuals from Africa, with a median income of approximately €137.54 per month, can only afford to attend a maximum of five events. In contrast, individuals from Europe, with a median income of €1,969.28 per month, can afford to attend up to 30 events. This highlights the impact of global income inequality on accessibility to such major events.

In the specific case study of Brazilian attendance, our analysis shows that the majority of the Brazilian population, particularly those in classes D and E, face considerable financial barriers. For instance, individuals in Class E, with a monthly income of €101.37, can only afford to attend a maximum of 10 events, given their budget constraints. The high cost of Olympic tickets, coupled with additional travel expenses, makes attending multiple events an unrealistic goal for lower-income families.

The findings of this study have several important implications. First, they highlight the need for initiatives to improve the accessibility of global events like the Olympic Games. Possible measures include subsidized tickets, travel grants, and community support programs aimed at lower-income groups. Such initiatives would help ensure a more inclusive and equitable participation.

Additionally, the model developed in this study can be applied to other large-scale sporting or cultural events, providing organizers with a valuable tool to enhance attendee experience and address logistical challenges. By optimizing event schedules and considering individual constraints, organizers can better accommodate diverse audience needs.

For future enhancements, it would be beneficial to reformulate the problem as a multi-objective optimization model. This approach would simultaneously maximize spectator preferences and minimize travel costs, providing a more balanced and efficient solution. Additionally, incorporating an option to filter by games of specific countries could further enhance the model, as spectators typically prefer to watch events featuring their own country during the Olympics.

In conclusion, the model presented in this paper not only enhances the individual spectator experience but also addresses broader issues of accessibility and economic efficiency. By leveraging mathematical optimization techniques, we can contribute to creating a more inclusive and enjoyable experience for all attendees of large-scale events.

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