Travel plan for tourists: minimum access path and route circuit in Jalapão State Park

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Abstract — This article presents the proposal for a model travel plan for tourists in the Jalapão State Park [PEJ - Parque Estadual do Jalapão], located in the State of Tocantins, Brazil. The research shows the use of the *Gurobi Optimizer* library in Python Software associated with using Miller-Tucker-Zemlin (MTZ) constraints to ensure a viable route circuit. Through the Traveling Salesman Problem (TSP), two viable optimal routes are presented for two research problems: i) minimize the distance of access to the PEJ from the city of Palmas -TO and ii) find an optimal route path for tourists considering some of the most relevant points of the PEJ. The study presents a viable solution to route problems and contributes with an actual model, showing that TSP and the use of restrictions MTZ can be adequate to solve these problems and others to be solved in PEJ.

Keywords— Gurobi, Routes, Tourism, Jalapão, Traveling Salesman Problem

I. Introduction

In recent years, the large flow of tourists seeking the state of Tocantins in Brazil is essentially guided by the notorious relevance of the Jalapão State Park [PEJ - Parque Estadual do Jalapão], located in the eastern region of the state. The PEJ is a conservation unit that concentrates on numerous tourist attractions, such as dunes, rivers, boiling water, and waterfalls. The park is considered one of the biggest tourist attractions in the state, and the number of tourists who seek to experience its charms grows every year. The Tocantins Nature Institute [1] reported that the annual tourist visits to PEJ skyrocketed from 6,464 to 55,579 in nine years, from 2012 to 2021.

Palmas, the capital of Tocantins, has become the point of arrival and departure for tourists from all over Brazil and the world. With a well-developed structure to receive tourists, such as hotels and airports, the city has been considered the gateway of tourism in the state. The routes for access from Palmas, as well as an itinerary to access the more than 30 attractions [2] of public access of PEJ, is something different and varies from the tourist's will, as well as from the itineraries predetermined by guides regularized by Naturatins. Unfortunately, considering the large influx of tourists, a travel itinerary without a plan and itinerary generates some setbacks, such as delays in the route, longer and more tiring circuits, loss of time, and overcrowding in the attractions, especially the boiling water.

Some authors, such as [7], [8], and [9], have already sought better routes for tourists, considering essential attractions in the world (such as Serbia and Cali) with the solution of travel itineraries and problems of distance routes. Others, such as [10], [11], [12], and [13], suggest applications for route plans, trips, tools, and itineraries or to help tourists in tourist attractions. Other studies, such as those by [14], associate Traveling Salesman Problem [TSP] added to heuristic methods to analyze the performance of the ant colony optimization algorithm for the Quasi-TSP, i.e., significant traveling salesman problems – NP-Difficult –, based on a practical problem in a tourist area.

The TSP is a famous combinatorial optimization problem developed to ensure viable optimal solutions [4]. The traveling salesman seeks to determine a single route in a graph or network, which can be classified as a network programming problem [5]. This type of programming problem is often associated with the goals of seeking the minimum path, the shortest path, flows, and task assignment. Some formulations of TSP can be elaborated with Miller, Tucker, and Zemlin constraints, known as Miller-Tucker-Zemlin [MTZ]. MTZ is one of the most common formulations for assigning subroute elimination [6]. According to the authors, the formation of the MTZ indicates a new set of variables that define the order in which vertex *i* is visited.

A travel plan was elaborated in this study, where through the formulation of the TSP, it was tried to solve two problems: to find the minimum path for access to the PEJ, starting from the city of Palmas – TO, and a second one that indicated an ideal route plan, considering the main tourist attractions of the park. In the research, the TSP optimization model considers a set of cities, restrictions, and distances between them, where the clerk (tourist) must discover the shortest route passing through each city only once [3]. Considering the conditions presented, can MTZ restrictions applied to TSP formulations bring actual viable routes for tourists to PEJ? The article's main objective was to propose a real model travel plan for PEJ tourists.

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II. MATERIALS AND METHODS

Created by State Law 1,203 of January 12, 2001, the PEJ is located in the eastern region of Tocantins and covers an area of 158,000 hectares [1]. According to the agency, PEJ is located between highways TO-030, 255, 130, and 110. The main entrance portals to the park are in the cities of São Felix and Mateiros, which give access to the main tourist attractions of the park. The distance from the city of Palmas varies according to the route, which can be done both in the North and South of the state. The route choice for independent tourists or guided drivers depends on the distance and the road conditions between the cities.

It was possible to trace the two problems by considering 24 points. The first problem concerns 12 possible cities for the access route to the PEJ, and the second problem considers 12 of some of the main tourist attractions within Jalapão.

For problem 01, the minimum path to reach the Parque Estadual do Jalapão was sought, departing from Palmas - TO.

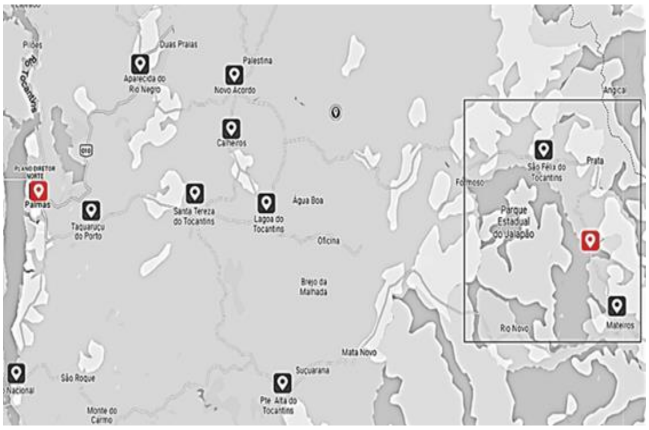

Fig.1: Overview of the path (Palmas - PEJ)

Fig 01 shows an overview of viable paths. From Palmas (origin) to PEJ (destination), ten cities were considered, located on the TO030, TO255, TO130, and TO110 highways. The city of Palmas was considered to be the starting point due to its relevance for national and international tourists. The planned city has an airport, hotels, and a guide recognized by Naturatins. With the city as the point of origin, the main cities of access to the PEJ were selected.

In Table 1, the cities were organized in ascending order of distance. However, it does not mean that the PEJ is the last access point because it is more distant since the TSP is treated as a network programming problem, and the objective is to make the circuit and return to the point of origin.

TABLE 1 CITIES ON THE ROUTE: PALMAS TO PEJ

1	Palmas
2	Aparecida do Rio Negro
3	Taquaruçu
4	Porto Nacional
5	Novo Acordo
6	Santa Tereza
7	Lagoa da Tocantins
8	Calheiros
9	Ponte Alta
10	São Félix
11	Mateiros
12	Jalapão

Distances between cities range from 16.5 km for the minimum route to 319 km for the maximum. Thus, considering the distance information, a Matrix was elaborated that synthesizes the distance between all cities.

TABLE 2 DISTANCE MATRIX – CITIES ON THE ROUTE

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	72,9	34,4	59,6	115	73,7	105	111	146	253	305	309
2	72,9	0	71,4	128	41,8	95,3	87,7	58,4	165	190	268	245
3	34,4	71,4	0	65,7	98,9	49,7	76,5	82,4	82,4	225	277	281
4	59,6	128	65,7	0	170	111	136	147	136	290	295	319
5	115	41,8	98,9	170	0	53,4	46,1	16,5	124	148	226	204
6	73,7	95,3	49,7	111	53,4	0	72,8	36,8	31	179	231	235
7	105	87,7	76,5	136	46,1	78,2	0	29,3	101	149	160	204
8	111	58,4	82,4	147	16,5	36,9	29,3	0	29,2	164	243	220
9	146	165	82,4	136	124	31	101	29,2	0	149	160	184
10	253	190	225	290	148	179	149	164	149	0	78,4	55,8
11	305	268	277	295	226	231	160	243	160	78,4	0	25,2
12	309	245	281	319	204	235	204	220	184	55,8	25,2	0

For problem 02, selecting tourist attractions within the PEJ was conducted. Once the points were defined, we sought to minimize the distance in the route plan for tourists, starting from the city of Mateiros. Thus, for the second problem, Table 3 presents some of the main tourist attractions selected.

TABLE 3 TOURIST ATTRACTION FROM MATEIROS

Ponto	Truistic Point
P1	Mateiros - TO
P2	Fervedouro do Rio do Sono
P3	Fervedouro dos Buritis
P4	Trilha Serra do Espírito Santo
P5	Fervedouro do Ceiça
P6	Fervedouro salto
P7	Fervedouro do Mumbuca
P8	Fervedouro Buritizinho
P9	Cachoeira do Rio Formiga
P10	Fervedouro Encontro das Águas
P11	Rafting no Rio Novo
P12	Cachoeira da Velha

Mateiros is considered the principal municipality that covers the boundaries of the PEJ in the state [1]. In addition to the point of origin (P1), 11 tourist points were selected to be visited in the circuit. Table 4 shows the matrix of distances between tourist attractions.

TABLE 4 DISTANCE MATRIX – TOURISTIC POINTS

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
P1	0	18	19,2	20	25	22,8	26	29	31,5	36	70	152
P2	18	0	1	26,6	6,9	4,5	15	10,7	14,4	11,8	62,3	138
P3	19,2	1,1	0	27,6	6	3,6	14,1	9,8	9,9	16,9	63,3	139
P4	20	26,6	27,6	0	33,6	31,2	41,7	37,4	41,1	45,5	35,1	111
P5	25	6,9	6	33,6	0	2,4	9,1	6,5	10,2	11,9	69,3	145
P6	22,8	4,5	3,6	31,2	2,4	0	10,5	6,2	9,9	13,3	66,9	142
P7	26	15	14,1	41,7	9,1	10,5	0	14,6	18,2	3	77,3	153
P8	29	10,7	9,8	37,4	6,5	6,2	14,6	0	8,5	17,4	73,1	149
P9	31,5	14,4	9,9	41,1	10,2	9,9	18,2	8,5	0	17,5	73,2	149
P10	36	11,8	16,9	45,5	11,9	13,3	3	17,4	17,5	0	80,2	156
P11	70	62,3	63,3	35,1	69,3	66,9	77,3	73,1	73,2	80,2	0	75,5
P12	152	138	139	111	145	142	153	149	149	156	75,5	0

The distances between the attractions vary from 1.0km on the minimum route to 156km at the maximum. Most of the points are boiling water; these are some of the main attractions of PEJ, and due to the large flow of tourists in PEJ, it tends to suffer from crowding and queues. Because of the pre-established limit of people and the route conflicts between the driving guides, these problems tend to occur especially between July and September, a period of little rainfall in the state.

a. Method and mathematical model

According to [5], the traveling salesperson must simultaneously visit all network nodes (cities, points, customers). Considering that a closed circuit can represent the problem of the traveling salesperson, we adapted the two problems where the tourist must pass through each city *n* only once, starting in city 1 (Palmas) and returning to the same starting point.

For problem 02, the objective is to depart from city n (Mateiros), situated in the Jalapão region, explore the various attractions, and arrive back at city n (Mateiros). The following information applies to both problems:

n = points (cities or tourist points)

$i = 1,\ldots,n$ Origins

$j = 1,\ldots,n$ Destinations

c_{ij} = cost of going from i to j

Decision variables:

$$x_{ij} = \begin{cases} 1 & \text{if the route includes a direct link between points } i \text{ and } j \\ 0 & \text{if it was not carried over } ij \end{cases}$$

In x_{ij}, these are binary decision variables, which assume values of 1 when the path interest is in the variable and 0 otherwise [5]. Thus, according to [4], the objective function of the traveling salesperson problem can be expressed as follows:

$$\min = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij}\, x_{ij}$$

For the objective function of the two problems presented, the Miller-Tucker-Zemlin (MTZ) constraints were used to eliminate the subroutes of the problems. Thus, it was considered that the objective function is subject to:

$$\sum_{j=1,\, i \neq j}^{n} x_{ij} = 1, \quad \forall i \qquad (1)$$

Where from $j = 1$ to n, i is different from j.
For all i of origin, origin, and destination only once

$$\sum_{i=1,\, i \neq j}^{n} x_{ij} = 1, \forall j \qquad (2)$$

Where from $i = 1$ to n, i is different from j.
For all j destination, origin, and destination only once

$$u_i - u_j + n x_{ij} \leq n - 1, \quad 2 \leq i \neq j \leq n \qquad (3)$$

$$u_i \leq n - 1, \quad \forall i = 2, \ldots, n \qquad (4)$$

$$x_{ij} \in \{0 ; 1\} \quad u_i \in N_0,\ i = 2, \ldots, n \qquad (5)$$

Constraints (1) and (2) show that if i differs from j, a given node (point, city) forces a connection where the next destination is not itself but a different node. Constraint (3) indicates the variable u for each node (point/city), the n-1 constraints to eliminate sub-routes, and $i \neq j$ for all i and all j, between 2 and n, provided that i and j differ. In (4), the upper limit is u_i. The constraint (5), where x_{ij} is binary for all origin and destination; $i = 2$ to n where there is no particular point, then choose 1.

In a way, these last three constraints impose that only one trip covers all points and not two or more disconnected trips that cover all points [15]. To solve the problems with the formulation of MTZ, we used the *Gurobi library*, version gurobipy-9.5.0, installed in the Python programming language program. *Gurobi Optimizer* is a library for solving linear optimization problems [16]. Although it is limited to solving more significant problems, the academic license was acquired through the author's institutional email at https://pypi.org/project/gurobipy/.

According to the mathematical model, the traveling salesperson problem was implemented in codes, which were summarized in 10 executions in gurobipy-9.5.0:

Problem Parameters (Number of Points)
Cost matrix (Tables 2 and 4)
Origin and destination point indexes.
Decision Variables
Objective Function
Constraints that ensure that each point will originate exactly once (1).
Restrictions that ensure that each point will be destined exactly once (2)
Subroute Elimination Restrictions (3), (4) and (5).
Run the model to find the optimal solution.
Prints the array of values.

Section 4 presents the feasible circuits found for each of the research problems. The section was divided into two topics: one for the results of problem 01 and the other for problem 02.

III RESULTS

a. Minimum path to access the PEJ

The result processing time was 0.30s. The solution to the problem explored 22 nodes, and six solutions were found, where the lowest cost from Palmas to Jalapão and back to the city of Palmas was 756.6 km, while the least viable route was 1935.2 km. The table shows the best circuit for tourists, where 0 represents a less possible path and 1 for possible paths.

TABLE 5 BINARY VARIABLES MATRIX – PROBLEM 01

01: 0 0 0 1 0 0 0 0 0 0 0 0
02: 1 0 0 0 0 0 0 0 0 0 0 0
03: 0 0 0 0 0 1 0 0 0 0 0 0
04: 0 0 1 0 0 0 0 0 0 0 0 0
05: 0 1 0 0 0 0 0 0 0 0 0 0
06: 0 0 0 0 0 0 0 0 1 0 0 0
07: 0 0 0 0 0 0 0 1 0 0 0 0
08: 0 0 0 0 1 0 0 0 0 0 0 0
09: 0 0 0 0 0 0 0 0 0 0 1 0
10: 0 0 0 0 0 0 1 0 0 0 0 0
11: 0 0 0 0 0 0 0 0 0 0 0 1
12: 0 0 0 0 0 0 0 0 0 1 0 0

The matrix of values shows the best route for tourists leaving Palmas to PEJ, and returning to Palmas, being the best circuit:

Circuit = [1, 4, 3, 6, 9, 11, 12, 10, 7, 8, 5, 2, 1]

The data shows that tourists leave the city of Palmas (1), go to Porto Nacional (4), Taquaruçu (3), Santa Tereza (6), Ponte Alta (9), Mateiros (11) and Jalapão entry point (12). The traveler returns through São Felix (10), Lagoa do Tocantins (7), Calheiros (8), Novo Acordo (5), Aparecida do Rio Negro (2) and Palmas (1); this is the shortest route, considering an optimal solution more viable. It is a satisfactory solution because it makes a closed circuit and passes only once through the selected cities.

b. Route plan for tourists in the PEJ

In issue 02, the solution ran in 0.34s, exploiting 516 nodes. In this problem, eight solutions were found, where the best viable was 319.1 km and the least viable was 517.7 km. Table 6 shows the matrix of binary variables, where it selects the best circuit with variable 1 for the best paths.

TABLE 6 BINARY VARIABLES MATRIX – PROBLEM 02

01: 0 0 0 1 0 0 0 0 0 0 0 0
02: 0 0 1 0 0 0 0 0 0 0 0 0
03: 0 0 0 0 0 1 0 0 0 0 0 0
04: 0 0 0 0 0 0 0 0 0 0 1 0
05: 0 0 0 0 0 0 0 1 0 0 0 0
06: 0 0 0 0 1 0 0 0 0 0 0 0
07: 1 0 0 0 0 0 0 0 0 0 0 0
08: 0 0 0 0 0 0 0 0 1 0 0 0
09: 0 0 0 0 0 0 0 0 0 1 0 0
10: 0 0 0 0 0 0 1 0 0 0 0 0
11: 0 0 0 0 0 0 0 0 0 0 0 1
12: 0 1 0 0 0 0 0 0 0 0 0 0

The data matrix shows the best route for tourists leaving Mateiros, taking the route, and returning to the point of origin. The best circuit for the route was:

Circuito = [1, 4, 11, 12, 2, 3, 6, 5, 8, 9, 10, 7, 1]

The data show that the tourist leaves Mateiros -TO (1) and goes to Trilha Serra do Espírito Santo (4), Rafting on the Rio Novo (11), Cachoeira da Velha (12), Fervedouro do Rio do Sono (2), Fervedouro dos Buritis (3), Fervedouro Salto (6), Fervedouro do Ceiça (5), Fervedouro Buritizinho (8), Cachoeira do Rio Formiga (9), Fervedouro Encontro das Águas (10), Fervedouro do Mumbuca (7) and returns to Mateiros (1); this is the shortest route, considering an optimal viable solution.

It was noted that the Cachoeira da Velha, even though it is the longest distance to the city of origin, was the third attraction selected in the circuit; this indicates that the viable options are not those that are closest to the points of origin, but those that contribute to the most suitable route possible.

c. Other general recommendations

It is suggested that more nodes be aggregated for the route of the first problem and a more significant number of attractants for the second. It is hoped that the research will bring new directions and proposals for models added to other heuristic methods that seek to solve real problems in the PEJ, especially those that seek to reduce crowds and wait lines to enjoy the attractions, such as the boiling water. Research is also expected to use the TSP to solve route problems, considering the number of daily tourists, the capacity of people for each guiding guide, and the route time, which varies from 2 to 5 days. If in doubt, contact: admrocha13@gmail.com.

III. CONCLUSIONS

The article presented a proposal for a model of a travel plan for tourists in PEJ, located in the State of Tocantins. With the application of the traveling salesperson problem, it was possible to solve two problems presented: minimizing the distance of access to the PEJ and, also, the optimal route path for tourists considering some of the relevant points of the park.

Although the article does not consider an itinerary with all the routes and tourist attractions in the PEJ, the study presents a feasible solution to each proposed problem and contributes an actual model for tourists to consider. In this way, if guiding guides also choose it, it becomes suitable.

The travel plan template is a real problem since all points can be accessed. However, it should be noted that not all entrances to these points are easily accessed, as there are other bottlenecks to be considered, such as: i) the climate defines the conditions of the roads between the cities and the access to the tourist points. Usually, road conditions are more restricted in rainy seasons with potholes and water and mud wells, making tourists opt for alternative access. The same applies in the summer, where the sandbanks limit access. Thus, there may be a variation of meters or kilometers between cities and tourist points.

The use of the *Gurobi Optimazer* library in the high-level Python programming language showed satisfactory results in the research. From a practical point of view, using these structured frameworks ensures greater accuracy and diffusion of alternatives of knowledge applied to network problem-solving. In addition, the proposed mathematical model meets the requirements applied to real-case models. The use of TSP with TMZ constraints is relevant to the application of the problem because, in summary, it has two advantages: i) the approach presents a complete graph with direct connections between cities and between tourist points; ii) TMZ constraints assume that each point will be origin and destination only once, eliminating subroutes that may extrapolate the results of distances; this implies that the results are satisfactory for the problem presented, but improving the TMZ formulation with more restrictions can improve research results with greater complexity.

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