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RESEARCH ARTICLE

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TRAFFIC SIMULATION: USE OF ROUND ABOUT AS A TRAFFIC FLOW ORGANIZER ELEMENT IN INTERSECTIONS OF THE PALMAS CITY, TOCANTINS

***Maurício Souza, Alexandre Tadeu Rossini, Glenda Botelho, Ary Henrique Oliveira**

Quadra ARNE 53 Alameda 10, 02, Res. Alamoana 403D, Brasil

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****Corresponding author: Maurício Souza,***

ABSTRACT

This paper presents results of intersection traffic simulation in the central area of the city of Palmas-TO, which shows great movement during peak time. The objective is to compare the efficiency of the use of the roundabout with other types of intersection, at times with greater and lesser traffic flow. Palmas, capital of Tocantins, is a planned city with wide avenues and intersections of arterial roads with roundabouts, initially planned to discipline traffic and reduce accidents. Although the roundabouts are a great tool for disciplining traffic, many residents complain about their inefficiency at busy times due to traffic bottlenecks at intersections. In view of these reports, an intersection was chosen in the central area of Palmas with problems related to the large flow of vehicles at a time with greater flow for the accomplishment of a set of traffic simulations through computational analysis. To develop the simulations, the graph theory concepts for data modeling and queuing theory were used to understand the behavior and creation of vehicle queues to simulate the problem context. The genetic algorithms concepts were applied under the models to obtain the best solution of the analyzes, based on the behavior observed in the traffic monitoring. The results of the computational simulation presented analytical conclusions about the intersection point of roads with the adoption of roundabouts, presenting itself as a support element for the definition of urban traffic guidelines and policies.

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INTRODUCTION

The Palmascity, in the Tocantins state, is the youngest and the last planned capital of the twentieth century in Brazil. It was designed by the architects Luís Fernando Cruvinel Teixeira and Walfredo Antunes de Oliveira Filho to house 1.2 million inhabitants with an expansion forecast of up to 2 million [1]. Although, currently, it has less than the maximum capacity foreseen in its project (currently estimated population of 272,000 inhabitants [2]), traffic problems are already recurring in roads around the Square of Sunflowers in peak times, especially due to the fact that this region concentrates several public institutions, such as Secretariats of Government, Legislative Assembly, Court of Justice and the Government Palace of Tocantins, as well as private institutions like banks, shops, offices, restaurants, etc. It is common for the population to question and informally discuss whether the roundabout is the best intersection alternative between roads for the city traffic, given the traffic jamoccurs during peak time. According to the US Transportation Department [3], the roundabout has two striking features, the first being a continuous flow controller, so it doesn't interrupt traffic at any time, and the second is functioning as a speed reducer, causing let the average speed of vehicles slow down as you pass it. In short, the roundabout does not stop the flow, but slows it down, helping to reduce accidents with fatalities. On the other hand, the roundabout decreases the flow of traffic and often causes discomfort for public transport users. Given this context, the challenge has arisen to computationally simulate vehicle traffic at roundabouts that concentrate a large traffic flow in rush hour. The simulation allows quantifying the efficiency of the roundabout and comparing the result with simulations of other types of intersections. It's important to highlight that this work adopted the definition of roundabout efficiency as the function of traffic volume between the entry and exit points [4]. The quality of an intersection can be measured by adopting different criteria [5]: efficiency, which is the quality of traffic flow; safety, which measures human and material damage resulting from traffic accidents; cost, which gets the financial value spent on deployment, operation and maintenance; speed, which refers to the average speed of vehicles at the intersection; capacity, which is the overall use of the intersection, measured in terms of vehicles released by it in the unit of time. This research concentrated its efforts to analyze the intersection efficiency criterion, that is, this work performs simulations in order to compare the number of vehicles served by the intersections in a unit of time. In this sense, the hypothesis that guided the research of this work was that the roundabout is the solution that presents the best efficiency for same level intersections for the Palmas city. Traffic simulators are essential tools for studying and planning the flow of vehicles on highways and cities. Its use allows to measure the efficiency of roads and intersection points, making it possible to compare the use of roundabouts with different design options. This work uses a traffic simulator together with the computational technique called Genetic Algorithm, to obtain the best results from the set of traffic simulations with intersection in roundabout in relation to signaling. The growth of the vehicle fleet and the disorganization of the roads are usually factors used for the study of the traffic. Computational simulation stands out as an appropriate tool for this study, especially when performed at an intersection identified as a critical point of incidence of local traffic. Therefore, it is included in the scope of this work to determine the behavior of this type of intersection through mathematical modeling, allowing traffic to be simulated computationally. This work demonstrates, by computational simulation, which type of intersection is most efficient in relation to the current and future fleet at Palmas-TO intersections. For the future estimate, a vehicle fleet forecast was performed using the curve polynomial adjustment technique. For the simulation, the SUMO simulator was adopted and a computational tool with genetic algorithms was implemented to optimally calculate the opening and closing times of the semaphoric intersections. Simulation results were compared by quantitative methods that measured the efficiency of intersections. Therefore, this work focused on the accomplishment of the following specific objectives for the demonstration of the most efficient insertion method: identification of alternative solutions to the roundabout as an organizing element of the traffic flow at intersections of the Palmas city; identification of techniques capable of implementing the simulation of intersection types; the definition of roundabouts in the vicinity of the Sunflowers Square that was observed to extract its mathematical model; collecting the data of intersection traffic flow, that was previously defined, through filming by an unmanned aerial vehicle (UAV); formulation of the mathematical model of the selected intersection for the computational simulation; and at the end, the indication of the most efficient insertion among the simulations performed.

THEORETICAL FOUNDATION

This section presents three fundamental concepts adopted to construct the representation of the object of study of this work in order to enable the organized and modeled experiments execution as described in the methodology. Firstly, the concept of queuing theory, fundamental for accounting of the flow of vehicles that travel under the roads and types of intersections studied at work, will be approached. Next, we will discuss the concept of graphs, useful for the representation of roads and intersections. At the end, it will be presented the metaheuristic of genetic algorithms, computational strategy adopted for processing the data collected from the observations, which were analyzed from the context model provided by the definitions previously addressed. The next subsections present a synthesis of the concepts used for the development of this work.

Queuing Theory: A queue forms when attendance is less than demand. The study of its formation and behavior is a branch of probability that has several applications, such as service provision, scheduling and traffic flow, focus of the research of this work. Queue Theory has been studied to analyze the phenomenon of queuing in order to predict its behavior and infrastructure. The basic characteristics of the queue process can be considered as: customer arrival process or demand, attendant service standard or supply, queue discipline or demand control, number of service channels, system storage capacity and service stepsnumber [7]. The Figure presents a generic example of queues and the scheme adopted in the development of this work. Figure 1 Queue model adopted for the representation of a vehicle traffic queue. Queue theory assists in problem solving in applications such as air traffic scheduling in airport; synchronization of traffic lights; mooring of ships in ports; line waiting for freight trains; vehicles at toll stations; determination of capacity in car parking yards; among others [5].

Graphs: Many everyday situations can be described by a diagram consisting of an arrangement of points with certain pairs joined by lines. The mathematical abstraction of situations of this nature can be represented through the concept of graph. A (finite) graph G is formed by a pair (V (G), A (G)), where V (G) is a nonempty finite set and A (G) a set of unordered pairs of elements, not necessarily distinct from V (G). The elements of V (G) are called vertices and the elements of A (G) are called edges [10].

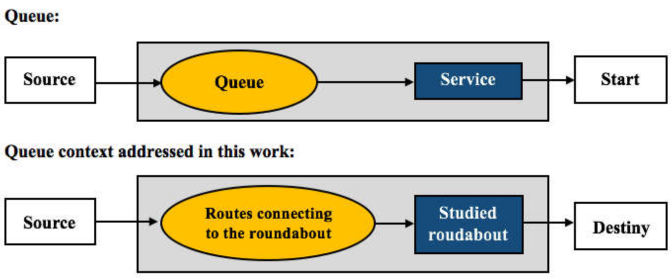
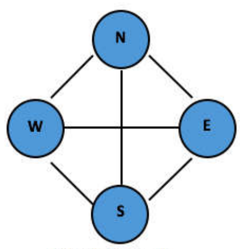


Figure 1. Adoptedqueue model for representing a vehicle traffic queue

Figure 2 presents an example graph that represents the possible directions for the traffic circle and traffic lights covered in this paper. The graphical representation of the graph in this case presents the vertices V (G) as points of origin and destination (N, S, E, W) and the edges A (G) that connect the vertices. The value 1 represents the existence of an edge between two vertices, while the value 0 defines the absence. Many everyday situations can be described by means of a diagram consisting of an arrangement of points with certain pairs joined by lines.

The mathematical abstraction of situations of this nature can be represented through the graph concept. A (finite) graph G is formed by a pair (V(G), A(G)), where V(G) is a non-empty finite set and A(G) a set of unordered pairs of elements, not necessarily distinct from V(G). The elements of V(G) are called vertices and the elements of A(G) are called edges [10]. Figure 2 presents an example of a graph that represents the possible directions for the flow of roundabouts and traffic lights covered in this work. The graphical representation of the graph in this case presents the vertices V(G) as points of origin and destination (N, S, E, W) and the edges A(G) that connect the vertices. The value 1 represents the existence of an edge between two vertices, while the value 0 defines the absence.



Graph Example

(N)orth:	W, S, E
(W)est:	S, E, N
(S)outh:	E, N, W
(E)ast:	N, W, S

Graph Table

$$A = \begin{bmatrix} 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 0 \end{bmatrix}, \quad B = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix}$$

Representation of the Graph in Matriz. Matrix Adjacency (A) and Matrix Incidence (B)

Figure 2. Graph used to represent possible traffic directions at roundabouts and intersections

Graphs can be directed or not directed, that is, they can have edge A(G) connecting two vertices V(G) in only one direction or in both directions. For example, when dealing with the context of traffic flow, it is necessary to know the directions of a road, and therefore, it is necessary to model the roads and flows by means of a directed graph [8]. In this case, the adjacency and incidence matrix gains values that were not previously represented, as shown in Figure 3.

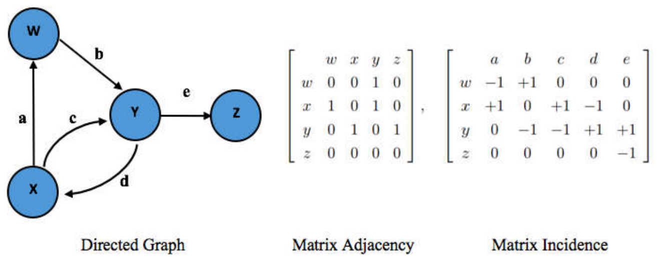


Figure 3. Directed graph used to represent directions of traffic on roads

With the possibility of valuation quantification in graphs, the size of an edge can represents the distance between anorigin vertex and a destination vertex. The vertices can represent the points of origin and destination connected by a path, represented by the edge between the vertices. In the context of vehicle traffic, the edge has a static value that denotes the distance between anorigin point and a destination point, while the number of cars that travel through this route characterizes the vehicles flow.

- Mutation of individuals to have randomness in the population: a percentage of cases is established in which a small fraction of the individual will be changed.
- Elitism policy to conserve better individuals: another percentage will be established to keep the best individuals during the process.

METODOLOGY

This work is characterized as an experimental and quantitative research, with inductive conclusions. Initially, a bibliographic survey was carried out on the simulation/simulator methods and tools, graph theory, queuing theory and genetic algorithm adopted in the development of the methodology. As it is an applied computer research, it was necessary to carry out bibliographic research on the area of traffic engineering. Then, the results and conclusions were obtained through experiments carried out with computational resources. The results of the experiments were quantified after performing the steps of data collection, mathematical modeling, simulation, mathematical interpretation and analysis of data extracted through sample observation. The inductive conclusion was obtained from the results generalization, that is, from the sample analysis, the result was induced to the entire universe of analysis. The next subsections present the methods, materials and tools adopted for the development of this work.

Table 2. Quantitative of vehicles observed in data collection

Recording Time	8am-8h05'	10am-10h05'	12am-12h05'	06pm-06h05'
East origin (E)	159	117	189	201
North origin (N)	98	120	173	153
West origin(W)	104	107	162	176
South origin Sul (S)	185	172	148	170
Total	546	516	672	700

Table 3. Options for routes followed by vehicles

Routes	Description	Routes	Description
S→S	south origin south destination	E→S	east origin south destination
S→W	south origin west destination	E→W	east origin west destination
S→E	south origin east destination	E→E	east origin east destination
S→N	south origin north destination	E→N	east origin north destination
W→S	north origin south destination	N→S	north origin south destination
W→W	west origin west destination	N→W	north origin west destination
W→E	west origin east destination	N→E	north origin east destination
W→N	west origin north destination	N→N	north origin north destination

Genetic Algorithm: The genetic algorithm, based mainly on John Henry Holland, is a type of evolutionary algorithm based on biology techniques such as heredity, mutation and natural selection [11]. It is widely used in artificial intelligence, because its results converge to an optimized solution and its implementation is easy. In a way, it can be generalized for various types of problems. Genetic algorithm encompasses some concepts such as, individual or chromosome, which is an arrangement of a possible solution to the problem, population which is the individuals set that form a generation, and finally, generation is each iteration of the genetic algorithm that tends to evolve. The steps presented below are fundamental for the execution of the algorithm.

- Population generation: initial stage where individuals are generated, usually at random, but some good individuals can also be pre-defined to converge more quickly to a better solution.
- Population classification: in this stage, individuals are classified based on the calculation of a fitness or assessment function that varies according to the problem.
- Stopping criterion: a point is established where the solution is good enough or a maximum number of generations is reached, whichever is first reached.
- Selection of father and mother individuals for crossover: there are different methods for choosing the individuals who will form a new individual, including roulette, tournament or ranking [12].
- Crossover of the old population to generate a new population: in this step the parents chosen in the previous step are merged. With this, part of the father and part of the mother are joined to form a new individual.

Data Collect: First, it was necessary to transport the data related to the intersections to the simulation environment. The samples were obtained through filming recorded by a UAV (Unmanned Aerial Vehicle), positioned perpendicularly to the intersection about 200m from the ground on a weekday during business hours. The filming was analyzed visually by a human in order to identify the mathematical model of the intersection, necessary for the simulation model. The insertion chosen as the study object was the intersection of the NS 2 road with the LO 3 road, located in the South Master Plan of Palmas-TO. The choice was due to the great movement of vehicles in large quantities in all directions, which favors the balance of the flow of all the roads that cross there. In addition, the intersection of NS 2 with LO 3 is positioned among other intersections that suffer with high vehicle flows, which makes it possible to expand this study to future works. In view of the filming, an absolute count of the number of vehicles per sample was carried out to identify which ones had the smallest and largest number of cars and, consequently, the smallest and largest flow. The time of data collection was determined based on information provided by a specialist, in this case, by the traffic superintendent of the Palmas city, Alexandre Guerreiro, who stated in an interview that the hours with the highest vehicles traffic in the city are between 12am and 12:30amand 6pm and 6:30pm. Thus, the collection of five samples of the intersection was defined in a Friday during business hours, according to Table 2.

It was not possible to carry out the sample analysis of 02pm hours due to technical problems. Analyzing the data collected, plotted in the graphic in Figure 4, it is possible to observe that there is a change in the direction of the intersection flow. In the morning, that is, in the samples from 8am and 10am, the largest vehicles flow originates in the South and the West. In the afternoon, the largest flows originate in the East and in the North. To represent the non-peak traffictime at the intersection, the 10am sample was considered, and for the peak hour, the 6pm sample was used.

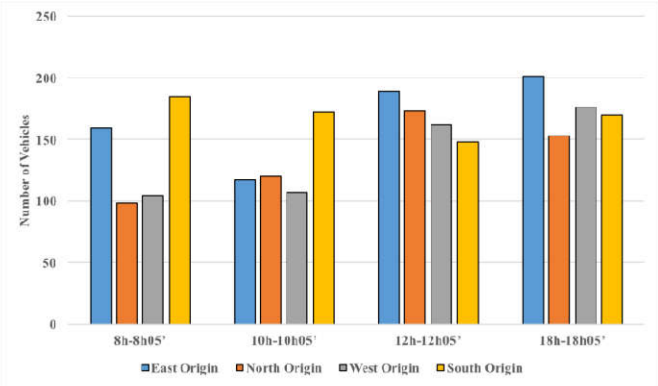


Figure 4. Observed vehicle flow in the north, south, east, west direction

Intersection Modeling: Traffic engineering is the sector that deals with the planning and geometric design of streets and highways with traffic operations, terminals, adjacent land. It also deals with integration with other transport types, aiming to provide safe, efficient and convenient movement of people and goods. Traffic consists of four basic elements[1]: users, vehicles, roads and the traffic control devices. Of this set, users and vehicles are the elements that the traffic engineer has little or no direct control over, requiring the design of a correct and efficient project of the roads and control devices to make traffic efficient and safe. An intersection is defined as the area in which two or more roads join or intersect, covering the entire space intended to facilitate the movements of the vehicles that circulate through it [4]. They are classified into two general categories: level intersections, where traffic stream crossings occur at the same level, and at different levels, where roads cross at different heights, usually via viaducts. After the stage of data collection, the stage of analysis and transposition of the vehicles' behavior of the roundabout to the mathematical model begins. In this stage, vehicle counting is performed to identify the origin and destination of each vehicle contained in the intersection sample. This analysis resulted in 16 routes followed by the vehicles, as shown in Table 3. The analysis and transposition of the vehicles' behavior from the roundabout to the mathematical model identified the origin and destination of each vehicle contained in the sample in 16 routes.

```
<trip id="0"   depart="0"    from="E_C" to="C_S"/>
<trip id="107" depart="0"    from="N_C" to="C_S"/>
<trip id="179" depart="0"    from="O_C" to="C_S"/>
<trip id="264" depart="0"    from="S_C" to="C_L"/>
<trip id="1"   depart="2.8"  from="L_C" to="C_L"/>
<trip id="265" depart="3.49" from="S_C" to="C_N"/>
<trip id="180" depart="3.53" from="L_C" to="C_N"/>
```

Figure 5. Example file with vehicle trips

The count of vehicle in relation to their routes for the 10am and 6pm samples is shown in Table 4, where the route identification is indicated as “origin→destination”, ie S→O: origin from the south direction and destination to the west direction. The count of the vehiclesnumber traveling through the roundabout was recorded in an “xml”[2] file used by the simulator to generate the route files for the simulation. The file recorded the information of the vehicle identification number (id), departure time, departure location and destination location, generating the path of each vehicle. Figure 5 presents an example of this “xml” file. To distribute the vehicles evenly during the simulation, the starting time of each vehicle was calculated as the total recording time divided by the number of vehicles. For example, 300 seconds of the sample divided by 30 cars from the north of the intersection to the south, it turns out that every 10 seconds a car left from the north to the south of the intersection. As the projection of the simulation for 5, 10 and 15 years was also considered, it was necessary to quantify the growth of the fleet in the Palmas city based on the growth obtained in recent years. In view of this, information from the Palmas fleet was obtained between the years 2008 and 2016 on the Denatran website [13], which are presented in Table 5. The values refer to the corresponding fleet on the last day of each year. The data in Table 4 were plotted in a scatterplot with a trend line as shown in Figure 6. This trend line was generated from the curve polynomial adjustment determined by Equation 1. The temporal evolution shown on the X axis (abscissa)can be observed. Time originates at the zero point, starting with the value one, the year representation begins, with the value one corresponding to 2008, the value 2 corresponding to 2009 and so on. This definition was made in such a way that the generated equation did not present extreme values. With the equation, it was possible to project the growth of the vehicle fleet and obtain an estimate for 5, 10 and 15 years. The orange dots on the graphic determine the growth estimate of the vehicle fleet.

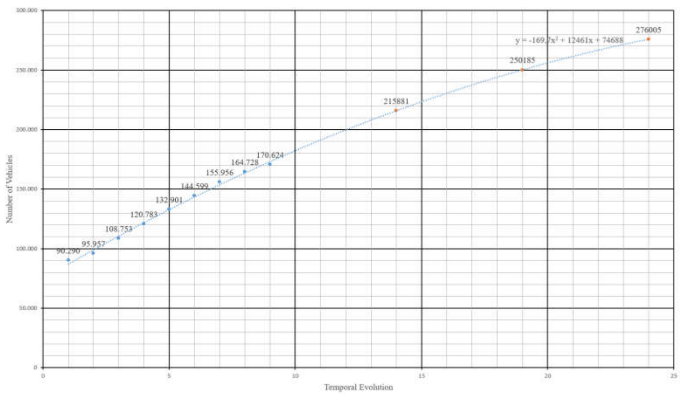


Figure 6. Evolution of the vehiclesnumber in the city of Palmas-TO

Equation1 $$y = -169{,}7x^2 + 12.461x + 74.688$$

It is important to note that the simulations were carried out considering the proportional growth in the vehicles number for each route. The forecast for the increase in the fleet in 2021 compared to 2016 is 26.53%; in 2026 compared to 2016 is 46.64%; and in 2031 the increase forecast is 61.78% in relation to 2016. Thus, the number of vehicles was calculated considering this increase and generating new travel files for the vehicles in the simulations. Table 6 presents the estimated number of vehicles for possible conversions for the non-peak time and was calculated considering the data obtained from the 10am sample; Table 7 presents the estimated number of vehicles for peak hours and was calculated considering the data obtained from the 6pm sample.

In the first and sixth columns are the origins and destinations of the trips, in the second and seventh columns the number of vehicles recorded in the filming and, in the others columns, the number calculated according to the increase in the fleet for the years 2021, 2026 and 2031. As can be seen, the values of the quantitative estimates were presented in the form of real numbers, after processing the equations. However, the simulator does not accept decimal values to represent the number of vehicles. It was necessary to perform a rounding up to an integer value by approximation.

[1] Institute of Transportation Engineers - https://www.ite.org/

[2]File type for map representation basedin eXtensible Markup Language (XML).

Table 4. Vehicles number and their routes observed in the samples of 10am and 6pm

Route	10am	6pm	Route	10am	6pm	Route	10am	6am	Route	10am	6pm
S→S	1	2	W→S	9	24	E→S	14	24	N→S	45	49
S→W	7	13	W→W	0	3	E→W	36	64	N→W	8	13
S→E	16	26	W→E	20	42	E→E	2	5	N→E	9	8
S→N	67	45	W→N	29	16	E→N	10	14	N→N	6	2

Table 5. Growth of the vehicle fleet in Palmas-TO

Year	Fleet	Year	Fleet	Year	Fleet
2008	90.290	2011	120.783	2014	155956
2009	95.957	2012	132.901	2015	164.728
2010	108.753	2013	144599	2016	170.624

Table 6. Future estimate of the number of vehicle fleets for possible conversions considering times of lower flow (off-peak)

Route	2017	2021	2026	2031	Route	2017	2021	2026	2031
S→S	1	1,27	1,47	1,62	W→S	9	11,39	13,20	14,55
S→W	7	8,86	10,26	11,32	W→W	0	0	0	0
S→E	16	20,24	23,46	25,87	W→E	20	25,31	29,33	32,34
S→N	67	84,78	98,25	108,33	W→N	29	36,69	42,53	46,89
N→S	45	56,94	65,99	72,76	E→S	14	17,71	20,53	22,64
N→W	8	10,12	11,73	12,93	E→W	36	45,55	52,79	58,20
N→E	9	11,39	13,20	14,55	E→E	2	2,53	2,93	3,23
N→N	6	7,59	8,80	9,70	E→N	10	12,65	14,66	16,17

Table 7. Future estimate of the number of vehicle fleets for possible conversions consideringtimes of higher flow (peak time)

Route	2017	2021	2026	2031	Route	2017	2021	2026	2031
S→S	2	2,53	2,93	3,24	W→S	24	30,37	35,19	38,83
S→W	13	16,45	19,06	21,03	W→W	3	3,80	4,40	4,85
S→E	26	32,90	38,13	42,06	W→E	42	53,14	61,59	67,95
S→N	45	56,94	65,99	72,80	W→N	16	20,24	23,46	25,88
N→S	49	62,00	71,85	79,27	E→S	24	30,37	35,19	38,83
N→W	13	16,45	19,06	21,03	E→W	64	80,98	93,85	103,54
N→E	8	10,12	11,73	12,94	E→E	5	6,33	7,33	8,09
N→N	2	2,53	2,93	3,24	E→N	14	17,71	20,53	22,65

With the estimated future values, it was possible to determine the travel time distribution of the vehicles, whose data are expressed in Table 8, for normal flow time, and in Table 9, for peak time. In the first column are the origin and destination of the trips; in the columns referring to the years are the number of cars, current and future, for each route and the columns labeled "Time" show the travel time for each year.

Computacional Simullation: Digital (computational) simulation is the use of computers and computational techniques to copy the behavior of a real system. To simulate is to subject models to tests, under different conditions, to observe how they behave [6]. The simulation may involve prototypes or models subjected to real physical environments. In the case of mathematical models, they are subjected to mathematical disturbances to assess the expected service condition. From the simulation, prototypes can be developed which, after the tests, can be used as the final product. Simulation of Urban Mobility (SUMO) is an open and free project maintained by the Transport Systems Institute in Germany, since 2001. It has a set of support tools that deal with tasks such as route location, visualization, network import and emission calculation [9]. Therefore, it includes tasks such as microscopic simulation, which models all agents explicitly; simulates multimodal traffic, such as vehicles, public transport and pedestrians; import or generate the time of traffic lights. In addition, this simulator has no artificial limitation on the size of the network and the number of simulated vehicles. SUMO has been used to solve a wide variety of problems, for example, evaluating the performance of traffic lights and choosing the vehicle route by evaluating eco-conscious routing based on the emission of pollutants.

Simulation of the intersection in use (roundabout): The project of the roundabout at the intersection of avenues LO 3 and NS 2 was obtained for the simulation. The project was assigned for this study by the Mobility Secretariat of the municipal government of Palmas-TO and can be seen in Figure 7. In addition to the project, for the reliable simulation of the roundabout, its mathematical model was obtained, represented by the behavior of vehicles in relation to their intersection routes. For SUMO to simulate the vehicle route, it was necessary to import maps of the “osm”[3] format using the NETCONVERT tool, converting the maps to a file in the “xml” format. The editing of the maps was carried out, later, by the NETEDIT tool of SUMO. Figure 8 presents the map used for the computational simulation of the roundabout project provided by the Urban Mobility Secretariat. The “osm” type map of the roundabout was obtained through the OpenStreetMap.org website. OpenStreetMap.org is similar to Google Maps but offers,as the differential, the possibility of exporting a map to the “osm” format. The map obtained obeys some real distances such as the length of the roads, the distance from the central islands and the diameter of the roundabout. However, some dimensions needed to be adequate, the width of the roads was adjusted in a standard way to 3.2 meters. It is important to note that a change was made in the roundabout map. The roundabouts used in Palmas-TO are classified as modern roundabouts, because the vehicle that is traveling inside has the preference. On the other hand, in the classic roundabout, the vehicle that enters has the preference. In this way, a higher priority was set for the inner lanes of the roundabout and a lower priority for the lanes that give access to the roundabout. Once the scenario was modeled and the travel file generated, as shown in Figure 5, the roundabout simulation could be performed. The final time was standardized to be determined with the identification of the last vehicle in the simulation to leave the roundabout, which means that all vehicles were served by the intersection, completing it in full.

[3]Open Street Map (OSM) - File Format

Table 8. Time distribution of trips for time with less vehicle flow (off-peak)

Route	2017	Time	2021	Time	2016	Time	2031	Time
S→S	1	300,00	1	300,00	1	300,00	2	150,00
S→W	7	42,86	9	22,22	10	30,00	11	27,27
S→E	16	18,75	20	10,00	23	13,04	26	11,54
S→N	67	4,48	85	2,35	98	3,06	108	2,78
N→S	45	33,33	11	18,18	13	23,08	15	20,00
N→W	8	-	0	-	0	-	0	-
N→E	9	15,00	25	8,00	29	10,34	32	9,38
N→N	6	10,34	37	5,41	43	6,98	47	6,38
W→S	9	21,43	18	11,11	21	14,29	23	13,04
W→W	0	8,33	46	4,35	53	5,66	58	5,17
W→E	20	150,00	3	66,67	3	100,00	3	100,00
W→N	29	30,00	13	15,38	15	20,00	16	18,75
E→S	14	6,67	57	3,51	66	4,55	73	4,11
E→W	36	37,50	10	10,00	12	25,00	13	23,08
E→E	2	33,33	11	18,18	13	23,08	15	20,00
E→N	10	50,00	8	25,00	9	33,33	10	30,00

Table 9. Time distribution of trips to time with the highest vehicles flow (peak hours)

Route	2017	Time	2021	Time	2016	Time	2031	Time
S→S	2	150,00	3	100,00	3	100,00	3	100,00
S→W	13	23,08	16	18,75	19	15,79	21	14,29
S→E	26	11,54	33	9,09	38	7,89	42	7,14
S→N	45	6,67	57	5,26	66	4,55	73	4,11
N→S	49	12,50	30	10,00	35	8,57	39	7,69
N→W	13	100,00	4	75,00	4	3,19	5	60,00
N→E	8	7,14	53	5,66	62	42,86	68	4,41
N→N	2	18,75	20	15,00	23	14,29	26	11,54
W→S	24	12,50	30	10,00	35	4,17	39	7,69
W→W	3	4,69	81	3,70	94	15,79	104	2,88
W→E	42	60,00	6	50,00	7	25,00	8	37,50
W→N	16	21,43	18	16,67	21	100,00	23	13,04
E→S	24	6,12	62	4,84	72	4,55	79	3,80
E→W	64	23,08	16	18,75	19	25,00	21	14,29
E→E	5	37,50	10	30,00	12	23,08	13	23,08
E→N	14	150,00	3	100,00	3	33,33	3	100,00

Simulation of Alternative Intersection: Some questions were analyzed for decision making on what type of intersection could replace the roundabout. One of the questions concerns the definition of which intersectiontype could replace the roundabout of the crossing of NS 2 with LO 3. As presented in Section 2, there are intersections in levels and in different levels. The Intersection Design Manual [4] discusses the use of each type of intersection and, based on it, the possibility of intersection at different levels has been discarded, as it is indicated for roads where the speed cannot be low, being suitable for expressways. The cost fact still exists, because intersection at different level is associated with a high cost. Among the intersections at levels, the possibilities vary from changing the use of the existing intersection, passing through the traffic lights of the intersection, until the complete change of the roundabout by another intersection. After consulting a specialist in Transport Engineering, Prof. Ma. Betty Clara Barraza de La Cruz, from the Architecture Course at the Federal University of Tocantins (UFT),the traffic light was indicated as a viable simulation alternative. In addition, she also contributed to the definition of its usage settings, because the traffic light allows different configurations. At the recommendation of the specialist, the traffic light was configured to work with four stages, two for traffic ahead and on the right and two for the left turn. Figure 9 shows the representation of the four stages of the traffic light with their possible movements. In order to optimize the closing and opening time of each stage of the traffic light, a control mechanism was developed using the meta-heuristic of genetic algorithm. This mechanism found the best set of time of the traffic light stages making the vehicles flow more efficient, in order to compare it with the flow through the intersection by roundabout. With the genetic algorithm, the different times of the traffic lights for the four stages shown in Figure 9 were modeled as individuals. Each individual is composed of a single chromosome containing 112 genes, which represents the number of units of time in the total traffic light cycle, that is, 120 seconds minus eight, number of cycles for yellow signals. The yellow signal for each stage was configured to run in two seconds, totaling eight seconds.

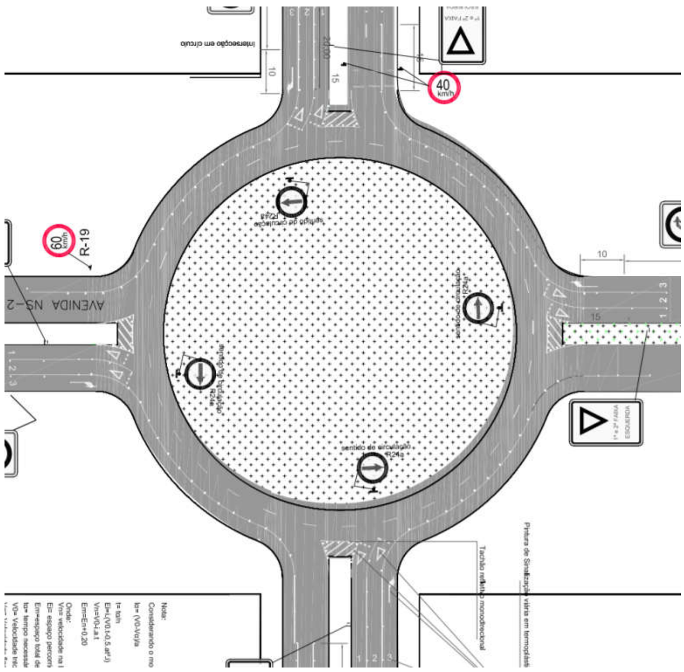


Figure 7. Intersection project in roundabout. Source: Palmas City Hall

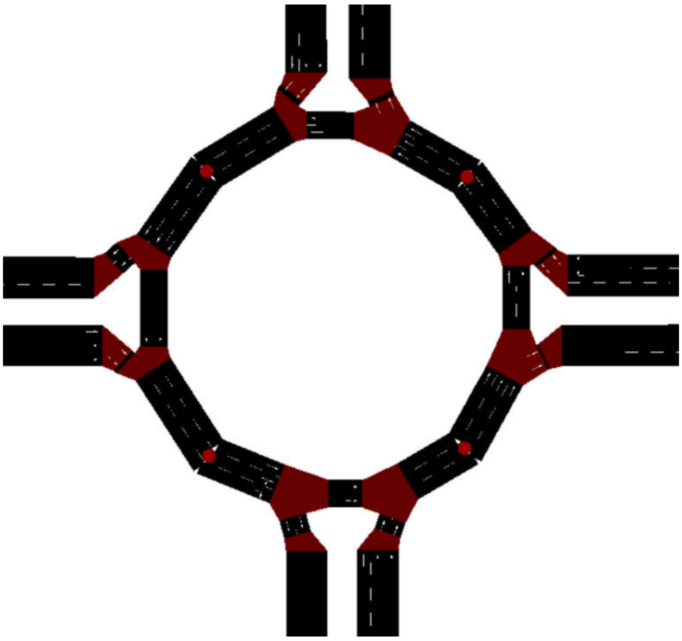


Figure 8. Simulated roundabout

Therefore, each gene corresponds to one second of the total traffic light cycle in green and red. Because it is fixed in time and always performed after the end of the green signal, the yellow signal was disregarded from the chromosome. The symbols 0, 1, 2 and 3 were defined as the genetic code of the chromosome. Thus, a chromosome, which is a sequence of genes, represents a certain solution, that is, it will be composed of the closing and opening times of the four stages of traffic light. More specifically, each chromosome is composed of four alleles[4], that is, each allele represents a traffic lights stage. The first allele corresponds to the stage represented in Figure 9a and is composed of all genes that store the symbol 0. The stage of Figure 9b is represented by the second allele, which is composed of the genes that store the symbol 1.

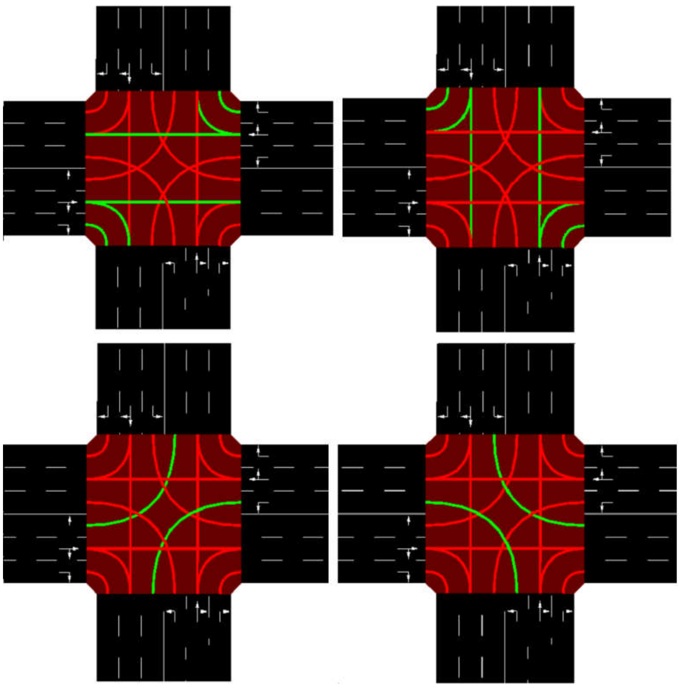


Figure 9. Traffic light stages adopted for the simulation of alternative intersection

The third allele corresponds to the stage represented in Figure 9c and is composed of all genes that contain the symbol 2. The stage referring to Figure 9d is represented by the fourth allele, which is composed of the genes that store the symbol 3. The initial population of the genetic algorithm was randomly generated by drawing the symbols 0, 1, 2 and 3 for each chromosome gene. Thus, a genes number of the allele for each individual in the initial population was randomly defined and the following depends on the outcome of the crossover. Step 1 of Figure 10 presents an example of initial population generation. To perform the crossover, it was necessary to define the individuals evaluation mechanism to generate an indicator that will be used by algorithm to select the crossover that generated a more optimized individual. The evaluation of an individual, in this work, was carried out in conjunction with SUMO and considers the execution time of the solution contained in its chromosome. The execution time of the solution is displayed by the moment when the last vehicle of simulation leaves the intersection. The shorter the simulation execution time, the better the evaluation or fitness of individual. To capture the final moment of the simulation, the loop detector was used, which is an existing resource in SUMO to obtain information about the vehicles used by it. Detector loops information are obtained in SUMO using the "traci.inductionloop.get Last Step VehicleIDs (loop name)" function. The function returns a list of vehicles that have passed it during the last simulation cycle. An example of the loops can be seen in Figure 11, where the rectangles represent each loop detector. They are positioned in order to capture vehicles information that pass through this lane.

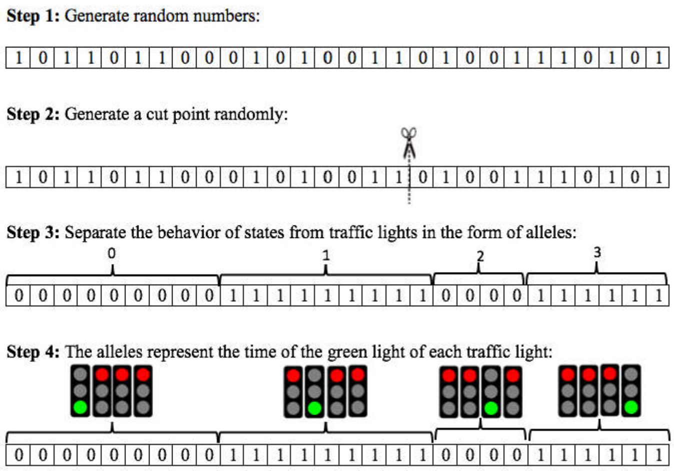


Figure 10. Processing of the genetic algorithm to find the most optimized selection of the traffic light based on vehicle traffic data observed in the field

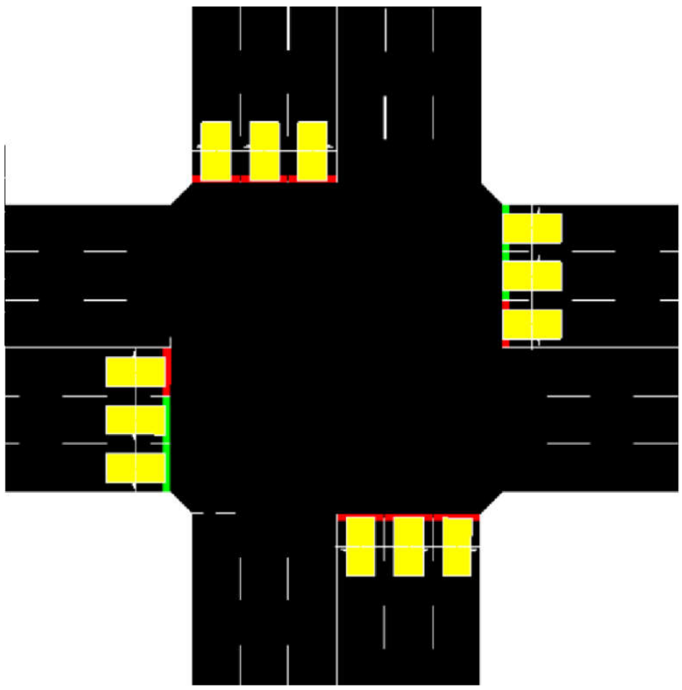
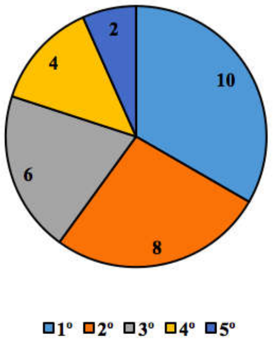


Figure 11. Example of detector loop

[4] Alleles are genes that come together to form a feature.

The selection method chosen was the roulette. This method considers the fitness value to select each individual. Initially, the fitness of all individuals of the current generation is added in order to obtain the number of roulette "houses". Then, the number of roulette "houses" are allocated in proportion to the fitness value of each individual. Then, an individual is selected by randomly selecting a roulette "house". In roulette technique, the best individuals are assigned higher values in the ranking in relation to their fitness. For example, in a population with 5 individuals, as shown in the simulation in Figure 11, a random number is generated, which in this case is in the range between 0 and 10. Thus, the first largest value that is greater than a random number will be chosen. For example, if the number 5 is randomly generated, the chosen number will be the 3rd best individual because the first number greater than 5 is the value 6.



	Fitness	Corresponding value
1°	459	10
2°	478	8
3°	501	6
4°	523	4
5°	556	2

Figure 11. Simplified example of performing the roulette technique

For the crossover of the individuals, the two parents are chosen, followed by the generation of a random cutoff point. From this cutoff point, the father's initial part is joined with the mother's final part. The crossover of individuals in the context of this work is carried out by selecting two individuals by crossing a point. The crossover method randomly draws a value between 0 and 112, which corresponds to the total amount of genes on the chromosome. The crossover returns a new chromosome with the genes from positions 0 to the crossover point from the chromosome of the first selected individual and from the crossover point to the end of the chromosome of the second selected individual. Individuals vulnerable to genetic mutation were randomly selected with a rate established at 30% per generation. Each randomly selected individual had up to 5% of their altered chromosome genes. The evolution results from the direct selection of the best individuals, according to their fitness. Thus, the best adapted individuals will make up the population of the next generation. The stopping criterion for the genetic algorithm was defined empirically in 10 generations. At the end of the execution of the genetic algorithm, the individual with the best fitness is chosen as the solution to the problem, that is, it means that the structure containing the times of the traffic light stages has been identified.

RESULTS AND DISCUSSIONS

Tests were carried out to compare the efficiency of the current roundabout of the intersection of the NS 2 and LO 3 roads with the efficiency of the traffic light intersection to replace the roundabout. Two different scenarios were analyzed: non-peak time (less vehicle flow) and peak time (greater flow). It was necessary to execute the genetic algorithm to obtain the optimized settings of traffic lights time for the non-peak and peak times for the current traffic, based on the estimates for the years 2021, 2026 and 2031, presented in Table 8 and Table 9. The result of the genetic algorithm execution returned the optimized configurations presented in Table 10, whose values, from left to right, are:

- Position 0: corresponds to the flow opening time in front and to the right, for the avenues to the east and west of the intersection;
- Position 1: corresponds to the flow opening time in front and to the right for avenues to the north and south of the intersection;
- Position 2: corresponds to the flow opening time on the left for the avenues to the east and west of the intersection;
- Position 3: corresponds to the flow opening time on the left for the avenues north and south of the intersection.

Table 10. Optimized settings of traffic light times obtained by the genetic algorithm

Year	Non-peak time	Peak time
2017	32, 38, 20, 22	45, 36, 14, 17
2021	25, 46, 20, 21	41, 35, 21, 15
2026	28, 45, 23, 16	50, 34, 17, 11
2031	26, 44, 20, 22	48, 35, 17, 12

Lowest Flow Time (Non-peak): The first test compared the efficiency of the current roundabout with its replacement by traffic lights during non-peak time. The data presented in Table 4, obtained by the sample between the period of 10am and 10:05am and filmed during a Friday, working day, were considered. Simulations for the current flow and for future projections were performed for the years 2021, 2026 and 2031. It is important to highlight that the values contained in the tables refer to the cycle times at the final moment of the simulation run at SUMO, that is, when all vehicles passed through the intersection and were served by the intersection. This means that lower values are more efficient than higher values because vehicles are serviced in less time. The simulation results are presented in Table 11 and SUMO screens carrying out the roundabout and traffic light simulations are in Figures 5.1 and 5.2.

Table 11. Tests results in times of low flow

Year	2017	2021	2016	2031
Traffic Light	452	566	632	694
Roundabout	471	568	627	665

The results show that currently the traffic light is a little more efficient than the roundabout for the time of less vehicle flow at the intersection of the NS 2 and LO 3 roads. However, as the fleet increases, the traffic light efficiency tends to decrease, and roundabout efficiency tends to increase. However, the results are very close. The simulation showed that the use of the optimized time setting of the traffic light for the lowest flow time does not bring interesting results, as shown in Table 12.

Table 12. Tests result of traffic light at times of highest flow with time setting for the lowest flow of vehicles

Year	2017	2021	2016	2031
Traffic Light	615	972	980	1112
Roundabout	479	610	665	720

Higher Flow Time (Peak time)

The second scenario tested was the flow of peak time. For this, the data presented in Table 3were considered. This datawas obtained by the sample between the period of 6pm and 6:05pm and filmed during a Friday, working day. Simulations were performed for the current flow and for future projections for the years 2021, 2026 and 2031. The simulation results are presented in Table 13.

Table 13. Tests result at peak time

Year	2017	2021	2016	2031
Traffic Light	466	516	588	660
Roundabout	479	610	665	720

For peak time, the results indicate that the traffic light is currently the most efficient solution, and will continue to be, becoming more and more efficient with the increase in the flow of vehicles. As in the first test scenario, using the optimized time setting of the traffic light for the time of highest flow at the time of lowest flow did not bring good results, as observed in the simulation results, shown in Table 14. Table 14 Tests result of traffic light at a lower flow time with a time setting for higher vehicle flow.

Year	2017	2021	2016	2031
Traffic Light	582	660	819	932
Roundabout	479	610	665	720

CONCLUSION

Throughout this work, various concepts and data on urban management and planning in terms of vehicle traffic at intersections were presented. Experts' opinions were presented on the design of intersections in roundabouts adopted in the city of Palmas-TO, as well as the computational concepts and techniques/tools used in the development of this work. According to the tests performed, the results demonstrate that using a single time setting for the traffic light makes this solution less efficient than the roundabout at the intersection on NS 2 with LO 3. However, the possibility of changing the traffic light settings for times of greater and lesser flow make it an interesting intersection for the studied crossing, as observed comparing the results expressed in Table 10 and Table 12. However, according to information provided in an interview by Alexandre Guerreiro, traffic superintendent of the Palmas city, the traffic lights currently installed in the city do not allow the configuration to change the times, making this option unfeasible in the city. It is important to note that this worklimited in the analysis of the intersection efficiency. There are other important variables that can be considered by managers in decision making, such as security and cost. Thus, it is concluded that the objective of this work to compare, via computational simulation, the efficiency of the roundabout in an intersection of arterial road in the Palmas city with other types of intersection was achieved. An important point, which cannot be overlooked, is that the simulation, even with a high degree of detail, may not reflect the totality of the real environment. However, if carried out rigorously, it presents ways and provides information so that new solutions can be implemented and cause improvements in the planning and management of cities. As future work, it is suggested to expand the scope to more than one intersection, starting to consider series intersections. Another possibility is to study the vehicles flow in the Palmas city taking the complete road infrastructure. There is also the opportunity to compare different roundabouts in different parts of the city, to justify their implementation and maintenance over the years, or to perform simulation of different roundabouts to those currently adopted in Palmas-TO. Finally, it is suggested to use the methodology exposed in this work to implement it in other cities.

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