A Prize-Collecting Approach for the Dengue Arc Routing Problem

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RESUMO

Neste trabalho, propomos o Problema de Roteamento em Arcos com coleta de Prêmios no contexto da Dengue (Dengue-PARP), que é o problema de encontrar rotas ótimas para veículos nebulizadores como uma medida de controle do crescimento da população de mosquitos. No Dengue-PARP, cada arco de um quarteirão tem um valor de prêmio relacionado ao número de casos de Dengue. O objetivo do Dengue-PARP é maximizar os prêmios coletados criando uma rota que que passe por um subconjunto de quarteirões. Este trabalho formula o Dengue-PARP utilizando um modelo de Programação Inteira (PI), submetido a experimentos computacionais em um conjunto de 39 instâncias do mundo real com casos notificados confirmados. A metodologia obteve soluções ótimas em 31 instâncias, sendo todas as 25 instâncias que contém até 372 vértices e 6 das maiores instâncias, que contém até 1212 vértices. O modelo também obteve soluções viáveis para as 8 instâncias restantes.

PALAVRAS CHAVE. Dengue. Coleta de Prêmios. Programação Inteira.

ABSTRACT

In this work, we propose the Dengue Prize-collecting Arc Routing Problem (Dengue-PARP), which is the problem of finding optimal routes for spraying vehicles as a control measure of the mosquito population growth. In Dengue-PARP, each arc of a street block has a prize value related to the number of dengue cases. The goal of the Dengue-PARP is to maximize the prize collected in order to create a route that covers a subset of blocks. This work formulated the Dengue-PARP as an Integer Programming (IP) model, subjected to computational experiments with a set of 39 real-world instances with confirmed notified cases. The methodology achieved optimal values for 31 instances, being all the 25 instances that contain up to 372 vertices, and 6 of the largest instances, containing up to 1212 vertices. The model also obtained feasible solutions for the 8 remaining instances.

KEYWORDS. Dengue. Prize-collecting. Integer Programming.

https://proceedings.science/p/157478?lang=pt-br

1. Introduction

According to the Pan American Health Organization (PAHO), in the year of 2021 a total of 1.324.108 cases of arboviral diseases were reported. Of those, 1.173.674 (89%) were Dengue cases, 131.630 were Chikungunya cases, and 18.844 were Zika. Between the Epidemiological Week (EW) 1 and the EW 19 of 2022, a total of 1.279.724 arboviral disease have already been reported, in which Brazil appears in first position as the country with the largest number of Dengue reported cases, achieving a total of 1.114.758 (90.9%) [WHO, 2022a].

The prevention, control, and combat of diseases caused by arboviruses, especially dengue, has been subjecting of great concern worldwide, as it is a reemerging disease caused by the transmission of Den 1, Den 2, Den 3, and Den 4 viruses through the *Aedes aegypt* and *Aedes albopictus*, which proliferates in the tropical regions of the world, comprising more than 1.8 billion of people susceptible to being infected [Negreiros et al., 2020].

The control of the mosquito can be done in two ways: eliminating adult mosquitoes, and eliminating the larval breeding grounds. In addition to precaution, where the focus is to make the population aware and eliminate possible recipients that could serve as breeding grounds for mosquitoes, chemical control is the most used approach. The chemical control consists in the use of chemical substances (for example insecticide) for vector control in the larval and adult stages.

The use of insecticides in public health is based on technical and operational standards, derived from a group of experts in pesticides of the World Health Organization (WHO), which recommends the active ingredients of the products and the doses for the various types of available treatments. The rational and safe use in vector control activities is essential, given that their indiscriminate use determines environmental impacts, in addition to the vector developing resistance to the products. An emergency approach to reduce the adult mosquito population, used in case of epidemics or endemics mainly in urban areas, is to apply insecticide using nebulizer equipment attached to vehicles, which we call throughout this work spraying vehicle, see Figure 1.



Figure 1: Nebulizer equipment attached to vehicle [SESA, 2022].

Spraying vehicles are useful for the control of outbreaks and epidemics, due to its high performance, 80 to 160 blocks per day depending on the equipment model. These applications must be constantly supervised to guarantee the indicated insecticide dosage in each visited street, since there is a series of operational factors, such as the equipment flow and vehicle speed [of Health, 2009]. To have the desired effect, the spraying must be realized in a period with correct conditions

to maintain the insecticide cloud staying close to the ground. The thermal inversion is generally produced in the morning, after the sunrise, and in the afternoon, just before sunset and, these moments are considered optimal to apply the insecticide with the spraying vehicle.

The sprayed insecticide has no residual effect and it is strongly influenced by wind and obstacles along the streets. The best effect is achieved when the densest insecticide cloud is at a distance of at most 100 meters from the equipment. As this distance is crossed, the effectiveness decreases, as a consequence of droplet drift influenced by factors of the environment. The cloud dispersion is illustrated in Figure 2.



Figure 2: Cloud dispersion of the application [of Health, 2009].

The instructions about the insecticide application are generally based on the ideal conditions of topology, the structure of the locality, and favorable winds. The operation is often harmed by unpaved roads, the presence of high walls, and high vegetation, in addition to headwinds. The application methodology must consider these limitations to obtain a good impact on the vector population. The vehicle must travel around each block before starting the next one, as shown in Figure 3.

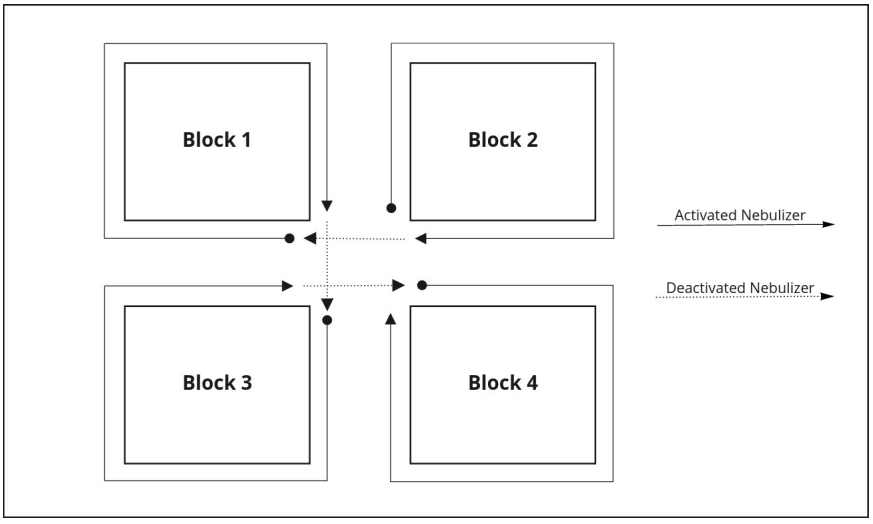


Figure 3: Vehicle pattern with nebulizer of Health [2009].

The complexity of the process of prevention and control of the disease is large, involving only in Brazil, annual expenses exceeding R$ 1.6 billions [Negreiros et al., 2020]. Such resources could be better allocated if the dengue logistics were better assisted by the tools of operations research.

To the best of our knowledge, we are the first to introduce the Dengue Prize-collecting Arc Routing Problem (Dengue-PARP), which is the problem of finding optimal routes for spraying vehicles with resource constraints. Prize-collecting Arc Routing Problems (PARP)s are arc routing problems where, in addition to the cost, there is a prize function that must be taken into account when an arc is serviced [Aráoz et al., 2006]. In Dengue-PARP, each block has a prize related to how critical the dengue outbreak is in that block measured by the number of Dengue cases. Moreover, the routes must satisfy the block-visiting pattern described in Figure 3 and must consider time and insecticide constraints. The Dengue-PARP goal is to maximize the prizes by setting a route that covers the most critical streets/blocks. In this work, we formulated the Dengue-PARP as an Integer Programming (IP) model, and tested on real-life instances with confirmed notified cases.

This work is organized as follows. In the next section, we present a review of the literature on machine learning and operations research tools applied in dengue logistics. Section 3 introduces an IP for the Dengue-PARP. Section 4 explains how instances were obtained and organized to validate the methodology. Section 5 reports the computational results. Finally, we make our concluding remarks and discuss some perspectives for future work in the last section.

2. Related Work

An extensive number of works in the literature use Machine Learning (ML) in the context of dengue [Shaukat Dar et al., 2015; Shakil et al., 2015; Hair et al., 2019; Sarma et al., 2020; Appice et al., 2020]. Some of the main problems addressed are generating Dengue diagnoses based on the patient's symptoms and clinical patterns, distinguishing dengue and its types in the early stage of disease progression and, dengue fever predictions in certain regions based on a set of factors, such as precipitation, rain, humidity, temperature, and others.

Lowe et al. [2015] presented a modeling procedure to quantify the benefits of including climate information in a dengue model for the 76 provinces of Thailand, from 1982-2013. The authors considered a set of factors that have a statistically significant contribution to the relative risk of dengue. The system provided an advanced warning that enabled the implementation of a more effective surveillance system. According to the authors, the proposed framework was flexible to be applied in any geographical setting, generating a more global approach to assessing the impact of climate variability and climate change on dengue risk.

Bannwart et al. [2013a,b] proposed numeric techniques using a genetic algorithm to solve the control model applied to Dengue prevention. Their model considered two kinds of measures: the cost of the chemical control (insecticide) and genetic (releasing sterile males in the environment). These works assume that the mortality rate of the mosquitoes is strongly related to the investment in control approaches. The experiments considered a time of 120 days and the results indicated that the amount of insecticide used was high considering the other approaches cited in the work. The authors presented an analysis considering each control and its impact on the rate of reduction in the mosquito population.

Cantane et al. [2015] presented a mathematical model to estimate the rate of population growth of mosquitoes. The authors observed that, without a control action, the population of mosquitoes could rapidly increase in short periods. The results of the experiments provide estimates of the life cycle of the mosquitoes are in perfect condition in nature and the model allows to measure an approximate number of mosquitoes for each scenario.

dos Reis et al. [2018], Florentino et al. [2018], and Helenice et al. [2018] presented methodologies for dengue control, including mathematical models that describe the population dynamics of the Aedes aegypti. A Genetic Algorithm (GA) was developed to obtain optimal strategies using an integration of different types of control. A Variable Neighborhood Search (VNS) determines optimized control strategies for the aquatic phase, which is when the mosquitoes are larva and pupa. The authors argue that the control during the aquatic phase reduces the environmental impact and the use of chemical control on large scale. The authors indicated that the presented methodologies have the potential as a tool for supporting decision-makers against arboviruses.

The works of Negreiros et al. [2008, 2011, 2020], to the best of our knowledge, are the only papers that apply operations research techniques for solving routing problems in the context of mosquito control. These works focus on the computational tool called Web Dengue, aimed at helping the Dengue control managers by providing a better visualization and coordination of control procedures. Among the methodologies, the authors developed an IP formulation to compute a periodical scheduling of vehicles. A GRASP heuristic was also developed to solve a real-life instance corresponding to the location of Praia de Iracema, Fortaleza.

3. Mathematical Formulation for Dengue-PARP

Consider a weighted, connected, and directed graph $G = (V, A)$, being $V = \{1, \ldots, n\}$ the set of n vertices, $A = \{(i, j) : i \text{ and } j \in V, i \neq j\}$ the set of m arcs. A block, in the Dengue-PARP, can be defined as a cycle C such that the arcs $(i, j) \in C$ are in clockwise order. The set B contains all blocks of the instance, and each vertex $i \in V$, that is not in a dead-end street, belongs to at least one block, while each arc $(i, j) \in A$ is in at most one block. The routes may start and end in any vertex of G, thus we augment G to $G' = (V', A')$ to include two artificial vertices, a source s and a target t, and a set of arcs such that $A' = A \cup \{(s, u), (u, t)\}, \forall u \in V$. The notation $B(i)$ is the set of blocks in which i belongs, and $V(b)$ is the set of vertices in the block b.

We set the Dengue-PARP entry as a tuple $(G', s, t, B, \lambda, \xi, f^T, f^I, i_{max}, T_{max})$. Each arc contains the values of dengue cases (λ), and distance (ξ). A time function f^T computes the time to travel an arc (f^T_{ij}) and the time to visit all the arcs of a block (f^T_b). The function f^I_b computes the amount of insecticide used to spraying a block. Lastly, consider the available amount of insecticide (I_{max}), and the maximum time of the route (T_{max}).

In the proposed model, there is a difference in the speed of the spraying vehicles. When the nebulizer is activated, the velocity must be constant and at most $15km/h$, being fixed according to the throughput of the nebulizer equipment. However, when the nebulizer is deactivated, the speed could be increased. In order to spray a block it is sufficient that the route contains at least one vertex from the same block. This is only possible due to the block-visitation pattern (Figure 3), that states that all the arcs of a block must be sprayed before starting another block. In this case, the traversed distance, elapsed time, prize collected, and amount of insecticide used to spray the block are consolidated by appropriate terms in the objective function and constraints. This is better explained next, where we present an IP formulation for the Dengue-PARP.

3.1. IP formulation

Consider the following variables:

- x_{ij}: A binary variable that indicates whether the arc $(i, j) \in A'$ belongs to the route;
- y_{ib}: A binary variable that is valued 1 if the vertex $i \in V$ is used as start point to spraying the block $b \in B(i)$;

With these variables, the Dengue-PARP IP formulation reads:

$$\max \sum_{i \in V} \sum_{b \in B} \lambda_b y_{ib} \tag{1}$$

subject to:

$$\sum_{j \in V' \setminus \{t\}} x_{sj} = 1 \tag{2}$$

$$\sum_{j \in V' \setminus \{s\}} x_{jt} = 1 \tag{3}$$

$$\sum_{j:(i,j) \in A'} x_{ji} - \sum_{j:(i,j) \in A'} x_{ij} = 0 \qquad \forall i \in V \tag{4}$$

$$\sum_{(i,j) \in A'} f_{ij}^T x_{ij} + \sum_{i \in V} \sum_{b \in B} f_b^T y_{ib} \leq T_{\max} \tag{5}$$

$$\sum_{i \in V'} \sum_{b \in B} f_b^I y_{ib} \leq I_{\max} \tag{6}$$

$$\sum_{i \in V(b)} y_{ib} \leq 1 \qquad \forall b \in B \tag{7}$$

$$\sum_{(i,j) \in A} x_{ij} \geq y_{ib} \qquad \forall i \in V(b), b \in B \tag{8}$$

$$\sum_{(i,j) \in (S,\bar{S})} x_{ij} \geq y_{ib} \qquad \forall S \subseteq V, i \in S, b \in B(i) \tag{9}$$

$$x_{ij} \in \{0,1\} \qquad \forall (i,j) \in A' \tag{10}$$

$$y_{ib} \in \{0,1\} \qquad \forall i \in V, b \in B. \tag{11}$$

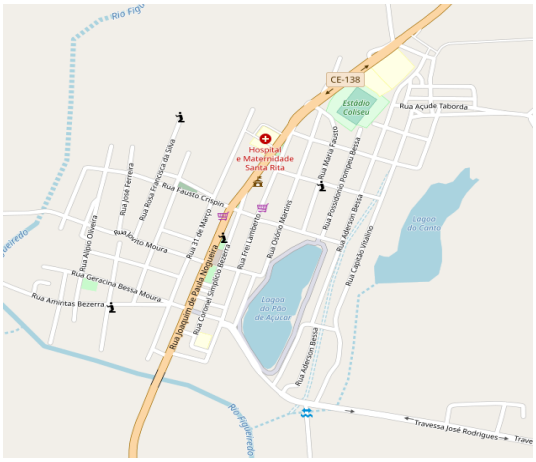
Each feasible solution for the IP model is a route starting at vertex s and ending in t obeying the limits of time and insecticide. The objective function (1) maximizes the prize of each arc in a block. Constraints (2)-(4) enforce flow conservation at each vertex. The constraints (5) limit the time used by the route, considering different velocities for when the vehicle is spraying or not. Constraints (6) limits the amount of insecticide. The constraints (7) and (8) ensure that at most one vertex is used as starting point to spray a block. Constraints (9) are subtour elimination constraints, ensuring the connectivity of the route. Constraints (10)-(11) set the domain of the variables.

4. Instance Generation

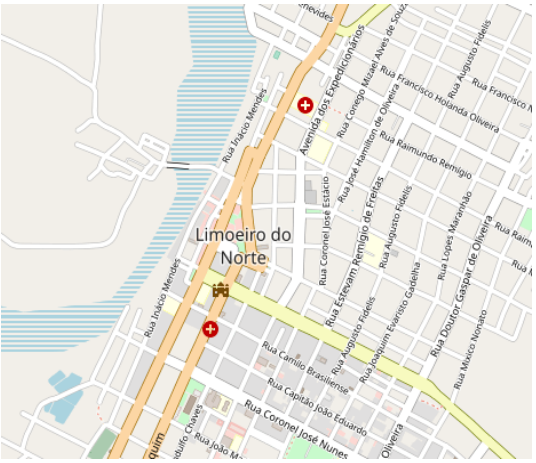
The first step in generating instances for the Dengue-PARP is the creation of the street network. This work adopted the maps available in the project open Street Maps (OSM) [Haklay e Weber, 2008], which is a collaborative mapping project to create a free and editable map of the world. Since OSM allows returning GPS coordinates of each vertex, we use this information to create the street blocks, and their corresponding directed cycles in clockwise orientation.

The set of instances contains 39 scenarios based on notified cases from the cities of Alto Santo and Limoeiro do Norte, in the state of Ceará - Brazil. These notifications were obtained from the Information System for Notifiable Diseases (SINAN) [Laguardia et al., 2004], from the years of 2015-2021, including information about the addresses of the patients. The addresses were applied

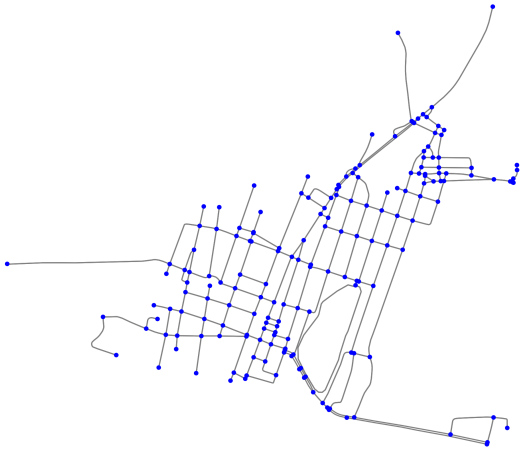
in the library OSMnx [Boeing, 2017] in order to obtain geocodes (latitude and longitude), and map them to blocks as the number of cases in the arcs (streets). The OSMnx receives as input a radius size to create the graph from a map. The arcs are the streets of the map and the vertices are the intersection of two or more streets, as shown in Figure 4. Each block of the graph is defined as a polygon, and an algorithm verifies if the Dengue notification collocation belongs to any polygon (block).



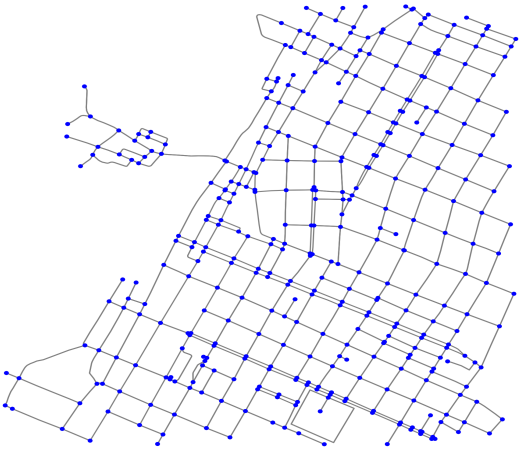
(a) Map of Alto Santo from OSM.



(b) Map of Limoeiro from OSM.



(a) Graph of Alto Santo.



(b) Graph of Limoeiro.

Figure 4: Example of graphs with 1000 meters radius.

Table 1 contains the instances of the generated set. The first column is the instance identification, each containing the following information: name of the city, size of the map, and year of the notified cases, respectively. The second to fourth columns are the number of vertices, arcs, and blocks. Column “Notified Cases” present the total number of cases mapped in the graph. Lastly, the column “Blocks with Cases” contains the proportion of street blocks that have notified Dengue cases.

instance	$\|V\|$	$\|A\|$	$\|B\|$	Notified Cases	Blocks with Cases (%)
notified-alto-santo-1000-2016	179	499	73	35	14
notified-alto-santo-1000-2017	179	499	73	194	37
notified-alto-santo-1000-2018	179	499	73	196	37
notified-alto-santo-1000-2019	179	499	73	196	37
notified-alto-santo-1000-2020	179	499	73	204	37
notified-alto-santo-1000-2021	179	499	73	218	37
notified-alto-santo-2000-2016	253	684	88	26	9
notified-alto-santo-2000-2017	253	684	88	174	30
notified-alto-santo-2000-2018	253	684	88	174	30
notified-alto-santo-2000-2019	253	684	88	174	30
notified-alto-santo-2000-2020	253	684	88	181	30
notified-alto-santo-2000-2021	253	684	88	195	31
notified-alto-santo-3000-2016	353	946	114	33	9
notified-alto-santo-3000-2017	353	946	114	198	25
notified-alto-santo-3000-2018	353	946	114	198	25
notified-alto-santo-3000-2019	353	946	114	198	25
notified-alto-santo-3000-2020	353	946	114	206	25
notified-alto-santo-3000-2021	353	946	114	225	25
notified-limoeiro-1000-2015	372	1063	152	18	8
notified-limoeiro-1000-2016	372	1063	152	26	11
notified-limoeiro-1000-2017	372	1063	152	50	17
notified-limoeiro-1000-2018	372	1063	152	51	17
notified-limoeiro-1000-2019	372	1063	152	66	20
notified-limoeiro-1000-2020	372	1063	152	163	30
notified-limoeiro-1000-2021	372	1063	152	168	32
notified-limoeiro-2000-2015	980	2866	443	174	7
notified-limoeiro-2000-2016	980	2866	443	337	9
notified-limoeiro-2000-2017	980	2866	443	527	12
notified-limoeiro-2000-2018	980	2866	443	543	13
notified-limoeiro-2000-2019	980	2866	443	875	14
notified-limoeiro-2000-2020	980	2866	443	2183	21
notified-limoeiro-2000-2021	980	2866	443	2316	22
notified-limoeiro-3000-2015	1212	3497	517	169	5
notified-limoeiro-3000-2016	1212	3497	517	336	8
notified-limoeiro-3000-2017	1212	3497	517	519	11
notified-limoeiro-3000-2018	1212	3497	517	533	11
notified-limoeiro-3000-2019	1212	3497	517	860	12
notified-limoeiro-3000-2020	1212	3497	517	2176	19
notified-limoeiro-3000-2021	1212	3497	517	2315	20

Table 1: Real instances information.

5. Computational Results

The model was implemented in C++, compiled with GCC version 7.5.0 using the optimization level -O3. The experiments were carried out on an Intel(R) Xeon(R) CPU E5-2630 v4 processor with 10 cores of 2.20 GHz each and 64Gb of RAM. The execution occurred on a 64-bit Ubuntu 18.04 Linux operating system. The full set of instances and experimental results obtained in this work can be accessed at https://github.com/cvaraujo/instances-dengue-ARP.

The Dengue-PARP IP formulation was implemented using Gurobi solver version 9.5.1, maintaining the default settings of its parameters. The maximum solution time for each instance was limited to 3600 seconds. The vehicle velocity when the nebulizer is activated is 250 meters$/$minute (approximately $15km/h$) and $21km/h$ while deactivated. The maximum time of the route (T_{max}) is limited by 120 minutes since this value represents the optimal interval time to apply insecticide in the morning or afternoon. The amount of available insecticide was $4000ml$, using $75ml$ per meter sprayed.

Table 2 exhibits the results of the IP model. The first column is the instance identification, each containing the following information: Name of the city, size of the map, and year of the notified cases, respectively. The second to fourth columns are the number of vertices, arcs, and blocks, respectively. Columns "LB" and "UB" present the "Lower Bound (LB)" (primal) and "Upper Bound (UB)" (dual) for each instance. The "gap $(\%)$" column displays the relative gap between lower and upper bounds. Columns "Nodes" indicates the number of Gurobi nodes. The last column displays the time in seconds needed to solve the model. The acronym TLE stands for "time limit exceeded", meaning that the solver was interrupted without reaching the optimum. The lines highlighted in dark gray (■) represent the instances in which the optimality was proved. The rows highlighted in light gray (■) correspond to the instances in which a feasible solution was found, but the duality gap could not be closed.

In Table 2, it is noticed that the IP model reached the optimum for 31 instances, being all the 18 from the city of Alto Santo, which contains at most 353 vertices and 946 arcs. From the 21 instances of Limoeiro, the optimal solution was reached for 13, some containing 1212 vertices and 3497 arcs. The average time for the 31 instances in which the optimal value was obtained was 128.4 seconds, and the number of Gurobi nodes is low, being on average 22.356, and for 24 instances less than 750 nodes.

For the other 8 instances in which the model did not close the optimality gap, the distance of the bounds was less than 1% in two cases, less than 18% for the other 2, and obtaining higher gaps for only four instances of the benchmark. Since the sub-tour elimination constraints were applied as lazy constraints, it was expected that the model would generate a high number of Gurobi nodes in the branch-and-bound tree.

Considering that we are solving real-world instances added to the increase in the number of vertices and arcs, there is an increase in the time needed to compute the optimal solution. It is also difficult for the model to improve the lower bound (feasible solution) and consequently close the gap on four of the largest instances. This fact induces that the model could benefit from a good warm-start solution, obtained by an effective metaheuristic.

To the best of our knowledge, no approaches that computes routes for nebulizer vehicles were found in the literature, making a comparison with our model infeasible. However, there is actually a negotiation with health government agencies to obtain real data on the use of nebulizer vehicles, among other actions, in dengue control.

Instance	$\|V\|$	$\|A\|$	$\|B\|$	LB	UB	gap (%)	Nodes	Time (seconds)
notified-alto-santo-1000-2016	179	499	73	180	180	0,0	1	0,1
notified-alto-santo-1000-2017	179	499	73	939	939	0,0	1	0,1
notified-alto-santo-1000-2018	179	499	73	947	947	0,0	1	0,1
notified-alto-santo-1000-2019	179	499	73	947	947	0,0	1	0,1
notified-alto-santo-1000-2020	179	499	73	982	982	0,0	1	0,1
notified-alto-santo-1000-2021	179	499	73	1 056	1 056	0,0	1	0,1
notified-alto-santo-2000-2016	253	684	88	126	126	0,0	1	0,0
notified-alto-santo-2000-2017	253	684	88	832	832	0,0	539	3,1
notified-alto-santo-2000-2018	253	684	88	832	832	0,0	539	3,2
notified-alto-santo-2000-2019	253	684	88	832	832	0,0	539	3,2
notified-alto-santo-2000-2020	253	684	88	861	861	0,0	539	3,2
notified-alto-santo-2000-2021	253	684	88	941	941	0,0	714	2,7
notified-alto-santo-3000-2016	353	946	114	163	163	0,0	1	0,1
notified-alto-santo-3000-2017	353	946	114	952	952	0,0	227	0,5
notified-alto-santo-3000-2018	353	946	114	952	952	0,0	227	0,5
notified-alto-santo-3000-2019	353	946	114	952	952	0,0	227	0,5
notified-alto-santo-3000-2020	353	946	114	988	988	0,0	227	0,5
notified-alto-santo-3000-2021	353	946	114	1 095	1 095	0,0	227	0,5
notified-limoeiro-1000-2015	372	1063	152	91	91	0,0	1	0,4
notified-limoeiro-1000-2016	372	1063	152	127	127	0,0	1	0,2
notified-limoeiro-1000-2017	372	1063	152	245	245	0,0	63	0,5
notified-limoeiro-1000-2018	372	1063	152	253	253	0,0	63	0,5
notified-limoeiro-1000-2019	372	1063	152	329	329	0,0	1	0,3
notified-limoeiro-1000-2020	372	1063	152	835	835	0,0	492 647	734,5
notified-limoeiro-1000-2021	372	1063	152	847	847	0,0	312	1,0
notified-limoeiro-2000-2015	980	2866	443	859	860	0,1	150 123	TLE
notified-limoeiro-2000-2016	980	2866	443	1 631	1 631	0,0	12 482	655,8
notified-limoeiro-2000-2017	980	2866	443	10	2 506	99,6	78 998	TLE
notified-limoeiro-2000-2018	980	2866	443	2 574	2 575	0,0	368 552	TLE
notified-limoeiro-2000-2019	980	2866	443	4 187	4 187	0,0	14 077	330,2
notified-limoeiro-2000-2020	980	2866	443	52	10 455	99,5	150 100	TLE
notified-limoeiro-2000-2021	980	2866	443	11 096	11 096	0,0	21 488	151,3
notified-limoeiro-3000-2015	1212	3497	517	693	840	17,5	123 813	TLE
notified-limoeiro-3000-2016	1212	3497	517	37	1 639	97,7	33 173	TLE
notified-limoeiro-3000-2017	1212	3497	517	2 231	2 467	9,6	82 621	TLE
notified-limoeiro-3000-2018	1212	3497	517	46	2 532	98,2	122 224	TLE
notified-limoeiro-3000-2019	1212	3497	517	4 122	4 122	0,0	56 962	1 067,9
notified-limoeiro-3000-2020	1212	3497	517	10 436	10 437	0,0	88 616	1 010,3
notified-limoeiro-3000-2021	1212	3497	517	11 098	11 098	0,0	2 306	9,9

Table 2: Results of the formulation for real instances.

6. Conclusions

This work proposed, formulated, and provided an IP for the Dengue Prize-collecting Arc Routing Problem (Dengue-PARP), which is the problem of generating routes for the spraying vehicles. The experiments were conducted on a benchmark of instances based on the cities of Alto Santo and Limoeiro, and using real notification cases from the years 2015-2021. The IP model was

capable of generating lower and upper bounds for all instances of the set, attaining 31 optimal solutions. The proposed methodology has a high potential for reducing routing costs and contributes to a more efficient allocation of resources concerning the control of arboviral diseases, which is especially relevant in municipalities with constrained budgets.

In future works, we will aim to study valid inequalities to improve the model and develop new exact and heuristic methodologies. Moreover, the model could be tested with real data from other cities. Another relevant research is to consider variants of the Dengue-PARP, considering a fleet of vehicles, multiple turns to apply the insecticide, and uncertainty parameters, such as the efficiency of the insecticide when applied in different time windows. In particular, we believe that the exact model would achieve better gaps if good warm-start solutions are provided.

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