Chapter

Optimized Planning and Management of Domiciliary and Selective Solid Waste: Results of Application in Brazilian Cities (SisRot®Lix)

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Abstract

We show a new technology to manage solid waste services through optimization methods (on sectoring, routing costs, and resources). This technology is called optimized planning and integrated logistics management (OPILM). It is being applied to Brazilian municipalities as it attends to their major natural features. The technology is formed by a framework of computational systems that uses optimization methods from sector arc routing and scheduling, fleet and staff scheduling, using also mobile smartphone apps. We present some of the results of real cases evaluated for residential refuse collection and selective waste collection in two Brazilian cities (Petrópolis/RJ and Bom Jesus dos Perdões/SP). The plan implementations achieved 17.9% from actual fixed and variable cost savings for sectors (vehicles and workers) and routes (time and distances) for residential refuse collection in Petrópolis/RJ. For the selective waste collection, we detail how we made our project to Bom Jesus dos Perdões/SP. We also present the returns considering costs involved in the management of the operational level and amortized by the investment required to use and apply the proposed technology for Petrópolis/SP.

Keywords: domiciliary waste collection, street sweeping, sector arc routing problem, spatial DSS, ERP

1. Introduction

Solid waste management deals with planning resources that are largely neglected by major Brazilian municipalities. The number of services related to the waste management in municipalities goes is more than 16. To mention some of these services, we have: domiciliary and selective waste collection (door-to-door), mechanical and human street sweeping, commercial and health waste collection, fair waste removal, cleaning and sweeping, container waste collection, painting gutters, and so on. All these services need plans and detailed establishment of the operation. Major work is done using unspecialized software tools, such as GIS-based software, but there is decision-making technology available, not well known by environmental engineers and managers, which can be suitable and adequate for better planning and optimizing resources [1].

For the domiciliary (door-to-door) waste collection, we define a sector as a defined region where staff (driver and collectors) do the domiciliary collection in a workday with the same weekly frequency. A circuit (shift, route, or collection trip) is the sub-region where the vehicle used by the staff travels until it reaches its waste storage capacity. A trip is a route between the garage, collection sector, and destination (typically a transfer station or landfill). Reinforcing the definition, a sector is composed of one or more collection circuits or routes that can be performed during a workday [2].

Most of the domiciliary and selective waste collection managers in Brazil plan their sectors and routes by using paper and drawing plans. The more effective and advanced ways of planning use AutoCad™, other tools incorporated by geoprocessors like Caliper™ [3], and apis from ESRI™, Here Maps, Open Street Map, Google Maps™ and others.

This work shows how we have solved these optimization and planning problems by using spatial decision support system (SDSS) technology composed of a software framework that allows users to design and manage mechanical collection and other service plans. To prepare the plans, we used SisRot® LIX, from Graphvs Ltda. [4], which calculates the collection sectors and street-by-street routes. The motion to use this system in counterpart to the others mentioned is that the SisRot®LIX is specialized in sector-routing problem, and it generality gives us back the opportunity to show the appropriateness of sector-routing for waste collection in different areas of waste collection management like domiciliary waste collection and domiciliary selective waste collection.

We present an application where we have re-sectored and rerouted the Petrópolis/RJ municipality, including the fleet, man hours, and overtime reductions. Finally, improvements are also presented for the new sectorization and optimization of selective waste collection sectors and routes in the city of Bom Jesus dos Perdões/SP, where the best placement of a recycle plant in the city was also studied.

We have organized this work into six sections. In Section 2, we illustrate the differences between capacitated arc-routing problems (CARPs) and SARPs. The third section presents the OPILM architecture with the SDSS SisRot® LIX features. Section 4 presents the results of the technology application. Section 5 studies the effect of savings in the waste collection system, taking as example the work done in downtown Petrópolis/RJ, here evaluated, and Section 6 summarizes the conclusions.

2. General sector arc-routing problem and its related problems

For better understanding the problems related to routing waste collection vehicles, we indicate below three of them:

Let us consider a strong-connected mixed graph $G(V\text{-}V_R, V_R, L\text{-}L_R, L_R)$, where V is the set of vertices, V_R are the required vertices, and L is the set of links ($L \subseteq E \cup A$, E —not oriented set of edges, A—oriented set of arcs, and $L_R \subseteq E_R \cup A_R$, E_R— set of required edges and A_R—set of required oriented arcs) that must be covered for the known garbage offer ($q_R > 0$). With this basic statement, the following problems consider the elementary needs to be solved by specialized methods [5].

There are three different methodologies of designing routes for waste collection: Chinese Postman Problem or CCP-based sectoring and routing, CARP-based solutions, and SARP-based solutions.

The CCP-based solutions consider that there are areas of collection that must be covered at certain times and on certain days. These areas can be covered in less than one workday through route design. The goal is to minimize the number of trucks required to cover the areas while joining (sectoring) different coverage areas in multiple trips to the landfill or transfer station. The routes are partially built by the Chinese Postman method, and a truck scheduling problem is performed to join the trips and compose sectors using a given fleet [6].

In the CARP-based solutions, the methods used consider a strongly connected positive-weighted graph as indicated previously. A fleet (homogeneous or heterogeneous) starts and ends at the garage ($v_0 \in V$) and passes through one or more intermediate facilities ($v_I \in V$), that is, a landfill or transfer station. This problem was first proposed as a symmetric graph $G(V, E\text{-}E_R, E_R)$ by Golden and Wong [7].

Using this approach, residential refuse collection applications and software for different cities worldwide were investigated by Ghiani et al. [8], and the most recent surveys on methods and their applications in garbage collection were conducted by Ghiani et al. [9], Han and Ponce-Cueto [10], and Mourão and Pinto [11]. With CARP solutions, the coverage of the area is not coordinated in a specific region, that is, shift contiguities are not guaranteed, or the same vehicle may collect in opposite places in a city, making managing the execution and measurement of daily processes complex [12]. Most recently, advanced methods have been developed by Boyaci et al. [13], considering fast lower bounds for CARP with intermediate facilities, and Janela et al. [14], considering balanced routes heuristics for MCARP.

The SARP was proposed by Mourão et al. [2]; it is considered an arc-routing problem (ARP), although it can be extended to node-routing applications for commercial and health waste collection. The SARP is, however, a more general problem than CARP as it includes all the problems of routing in arcs and nodes either with or without intermediate facilities [15]. In the SARP, trip contiguity, connectivity, and network compactness in a sector are considered objectives to be achieved by the final sector circuits covered by the routes, considering workload and fleet capacity constraints [16].

SARP resolutions are found by using clustering-based heuristic algorithms from generalized heterogeneous group assignments (sectors and circuits), and the Mixed Rural Postman Problem (MRPP) was applied to the circuits by Batista et al. [17] and Corberán et al. [18]. CARP heuristic method modifications have also been used by Corberán et al. [18]; they have been used by Ghiani et al. [19, 20] in zoning. Wølk and Laporte [21] used CARP with districting for waste collection in Denmark, and Boyaci et al. [13] applied fast upper and lower bounds for CARP with intermediate facilities and deadline methodology to large-scale world city instances. SARP was investigated by Mourão et al. [2], Rodrigues [15], and Cartinhal et al. [22].

In **Figure 1**, we can see an example of two circuits (trips) in the same collection sector: the chart on the left indicates the first trip (first circuit), starting at the garage, passing through the sector to collect, and ending at the disposal site. The chart on the right shows the second trip, starting from the end of the previous trip (transfer station), passing through the collection sector, and returning to the disposal site for unloading. The routes between garage and sector, sector and transfer station, and then transfer station and sector can be optimized by the "shortest path" or the "fastest path."

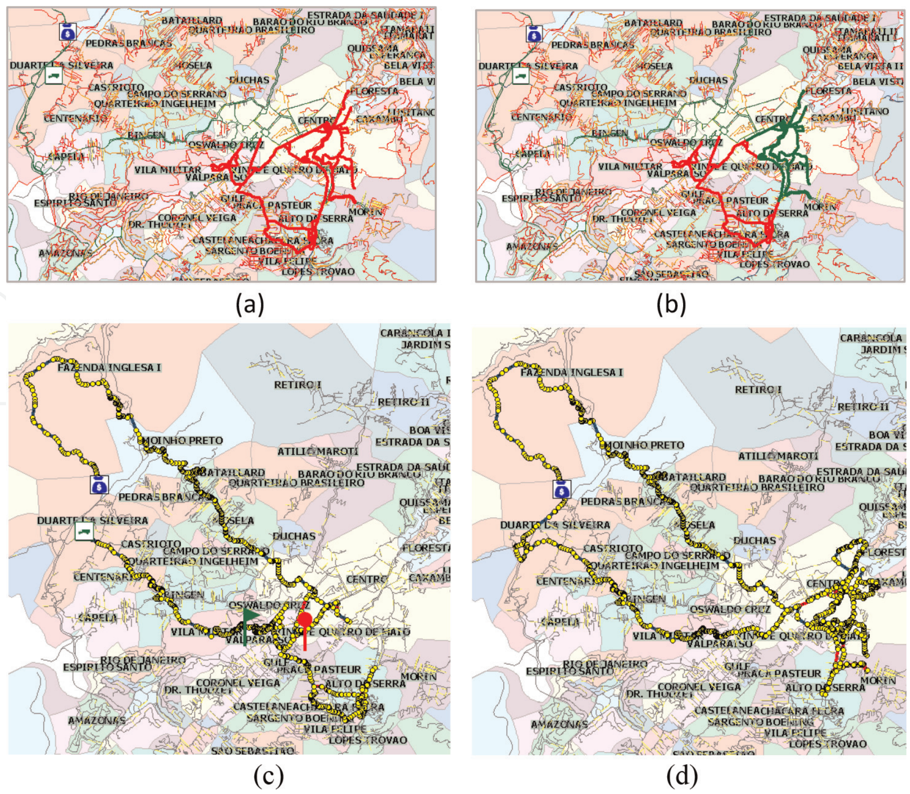

Figure 1.
Sector 220 and its circuits with routes for each circuit. (a) Sector 220 – Petropolis/RJ. (b) Circuits of the sector 220, (c) Sector 220 first trip, (d) Sector 220 second trip.

3. DSS-OPILM and SisRot® LIX features

The OPILM SisRot® LIX has been in development since 1989. Its scheme (**Figure 2**) presents the operational architecture of a set of computer systems that integrate through the web, allowing for optimized SWM (solid waste management)

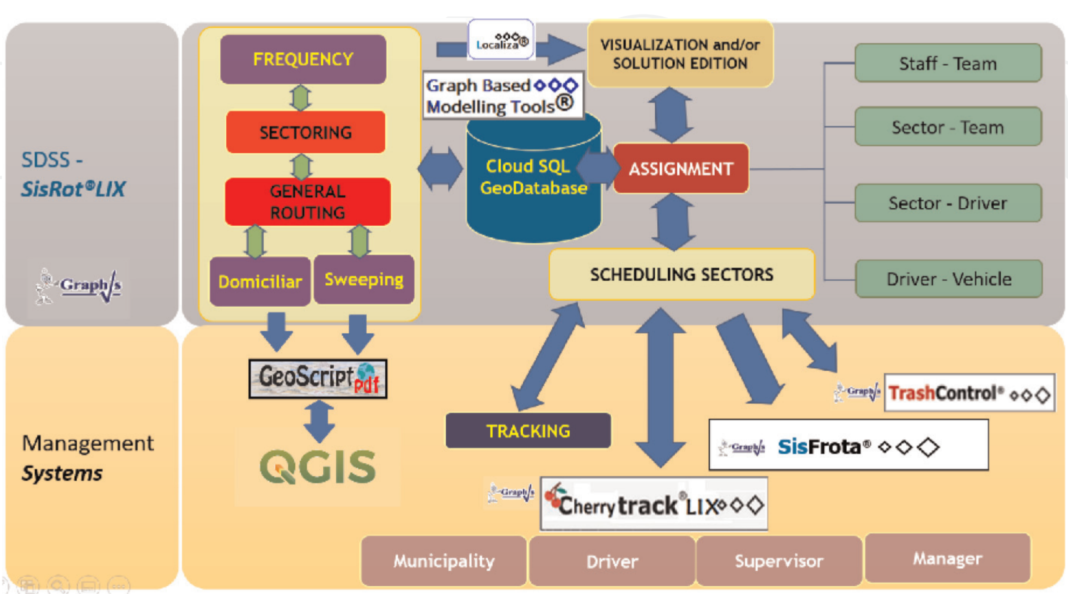

Figure 2.
OPILM architecture of the framework of computational systems for SWM [4].

and planning the different services to be performed. The system architecture is closely related to the conceptual DSS design model proposed by Klashner and Sabet [23] and the architecture proposed by Negreiros et al [24] and the web based framework developed to dengue control (webdengue) [25]. The core of the framework, corresponding to theory and analysis, includes the SARP system, which composes the algorithms for capacitated sectoring and routing, which are executed either manually or automatically. Heterogeneous sectoring is performed by heterogeneous capacitated centered clustering math heuristics, and the routing phase is performed with the mixed rural postman and movement prohibition reduction methods. These algorithms are executed according to the application (residential or selective domiciliary collection or human/mechanical street sweeping). The sectors and routes are part of the process final decision, and they are visualized through multigraph diagrams with movement/load/time/distance descriptions, multi-scaled vector maps (in different file formats), and street-by-street descriptive spreadsheets (in the XLS file format).

To better understand the OPILM in the portion of the SisRot®LIX, as shown above in **Figure 2**, a set of computational resources and parameters that govern the operational conditions in the field are necessary, as listed below:

1. Graph-based modeling system to network generation and editing, inclusion of constraints, editor connected with the associated roadmap shapefile (.shp)

2. Network-isolated vertices, strong connectivity, and number of components verification

3. Required street segment assignment and edition.

4. Definition of street features (Road, ave., street, etc), zip codes, numbers min and max of each street segment, and so on.

5. Editable load assignment spreadsheets per street segment (according to area population or proportional production per meter); the rate of waste generation per capita/region or by distance traveled (m); in the absence of this information by the operator SisRot®LIX being integrated into the Brazilian census map, which can determine the rate of waste generation by population density or by real estate

6. Inclusion and editing of special collection points and specific cargo (containers, fairs, accumulation points, customers)

7. Inclusion and editing "pulls:" there are roads taken by collectors, who collect the garbage up to the vehicle, either due to the physical limitation of the way the vehicle cannot cross it or because it has little or no waste; SisRot®LIX treats these roads for optimization, either disregarding them on the route (traffic impossibility) or using them (roads with little/no waste generation) if the calculated route is the most economical with traffic on them.

8. Editor to reformulate sectors and circuits

9. Location of the origin(s) and destination(s) of the vehicles: SisRot®LIX optimizes the operation with several garages and/or landfill/transfers (multi-origins and multi-destinations).

10. Slope of the road by using the spatial coordinate height (possibility to use generalized windy rural postman problem)

11. Vehicle load capacity (mixed fleet: vehicles can have the same or different loads)

12. Duration of the team's workday (household collection, manual/mechanized sweeping, and collection of swept garbage)

13. Vehicle speeds empty, full, collecting or deadheading

14. Collection discharge time at the landfill or transfer station

15. Edition of forbidden turns

16. Paths with/without forbidden turns

17. Mixed node and arc-routing methods (Generalized Rural Postman Problem in mixed networks) [16]

18. Multiple collection in arcs (special streets) in different trips.

Some characteristics of the solutions:

1. It is possible to optimize the selective and punctual selective collection routes (eco points, containers, bags resulting from sweeping, street fairs, monuments, hospital, etc.).

2. Vehicle routes are generated with a minimum of "U" returns and maneuvers to the left or right: less execution time and less effort from the driver, as well as keeping the service as continuous as possible.

3. Balanced trips: the routes can be optimized so that the loads collected between trips in the same sector are close, favoring the reduction of total workforce time.

4. Real-time tracking/visualization of vehicles, "lutocares," and any equipment and comparison to what was planned.

5. The routes between garage and sector, sector and disposal, and disposal and sector can be optimized both by the "shortest path" and the "fastest path." The section of the route that comprises the collection service itself, within the sector, is always optimized by the "shortest path."

6. The sweeping bags can be programmed by the sweeper every "*x*" meter and always close to corners. The route of the vehicle that will collect the sweeping bags, as well as the route of the vehicle used to take and pick up the sweepers for the sectors, is also optimized using a node-routing system, SisRot®FULL [4].

7. "Lutocar" tracking: any tracker can be incorporated into the system, allowing to monitor the execution of the sweeping service in real time. Any other equipment can also be tracked and incorporated into the system.

8. Assignment of teams of collectors to sectors, vehicles to sectors, and drivers to sector.

9. Zone-to-sector frequency definition and assignment.

10. Visualization and map/descriptive reports of zones, sectors, circuits, and frequency in different formats (KML, PDF, XLS).

11. Visualization and map/descriptive reports of routes in different formats (multigraph, animated, KML, PDF, XLS, and many others).

There is other arc routing software available in the market like TRANSCAD® [3]) and RouteSmart® [26] (from RouteSmart Technologies™). As can be seen in Environmental Expert site [27], there are many other platforms for waste management, analysis, monitoring, and planning using sensors (Smart sensors, watchdog, RFID tags, smart button) using specific modules for asset management, waste monitoring, route planning and fleet management from Sensoneo™ [28], and route planning from EasyRoute™ [29]. This late software are not arc routing based, they were built to accomplish point-to-point bins in domiciliary waste removal.

4. Designing and monitoring of sectors and routes

In this section, we consider the two types of results we obtained by using the OPILM SisRot LIX©. The residential refuse collection and domiciliary selective waste collection results are detailed in the following subsections.

4.1 Household refuse collection

With a population of 307 thousand inhabitants [30, 31], Petrópolis-RJ is a well-known touristic city; it has 48 collection sectors with an average of two collection circuits per sector. Five sectors were performed by the concessionaire downtown. The June 2020 data (without optimization) of these sectors were informed by the managers of the local concessionaire as follows:

1. Sector identification: Sectors 220, 221, 222, 223, and 224 (**Figure 3** left)

2. Collection through 9-t "stump" compactor truck with a maximum collection load of 9.3 t for each trip can be used per sector

3. Collection frequency: night and daily (Mon-Sat)

4. Each sector required two trips (circuits) per vehicle to be fully covered, with the first trip being garage→sector→transfer station and the second trip being transfer station→sector→transfer station.

5. Average ± Std of garbage total production per sector (five sectors): 12,34 ± 3,63 t/sector (Mon: 15,56 ± 4,21 t/sector) and (Tue-Sat: 11,64 ± 3,08 t/sector)

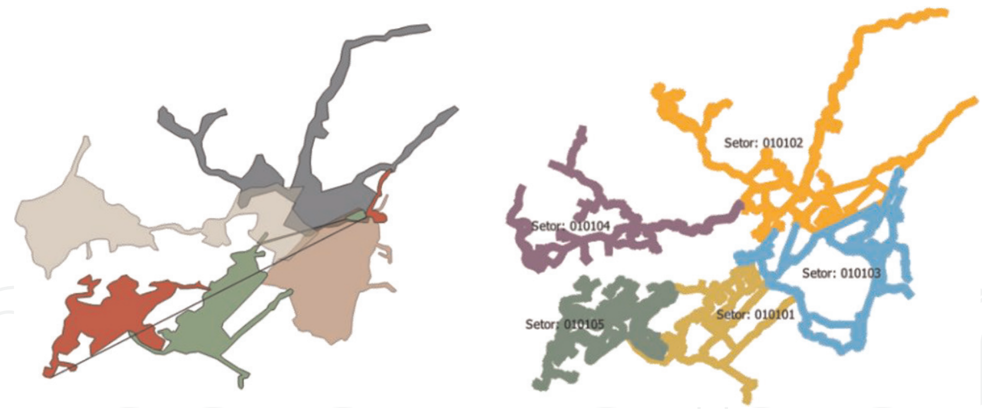

Figure 3.
Maps indicating the division of operation in downtown Petrópolis-RJ, considering at right previous sectoring (overlapping) and new coverage after project's intervention.

6. Total average daily distance traveled by fleet: 455 km/d (Mon: 465 km/d) (Tue-Sat: 450 km/d)

7. The average balance between daily trips: 90.5% (Mon: 9279%) and (Tue-Sat: 89.52%)

8. Team: five drivers and 15 collectors operate (one driver + three collectors on average in each sector)

9. Average ± Std collectors' efficiency (during collection): 823,02 ± 252,74 kg/man-h (Mon: 917,03 ± 312,85 kg/man-h) and (Tue-Sat: 802,35 kg ± 232,99/man-h); three collectors on average.

10. Collectors' average ± Std efficiency – with three collectors: 849,46 ± 211,01 kg/man-h; with four collectors: 581,59 ± 256,28 kg/man-h.

Figures 3–7 present the planning process to rearrange actual sectors and routes for the concessionaire. The development of the plans considers the unique precedence of

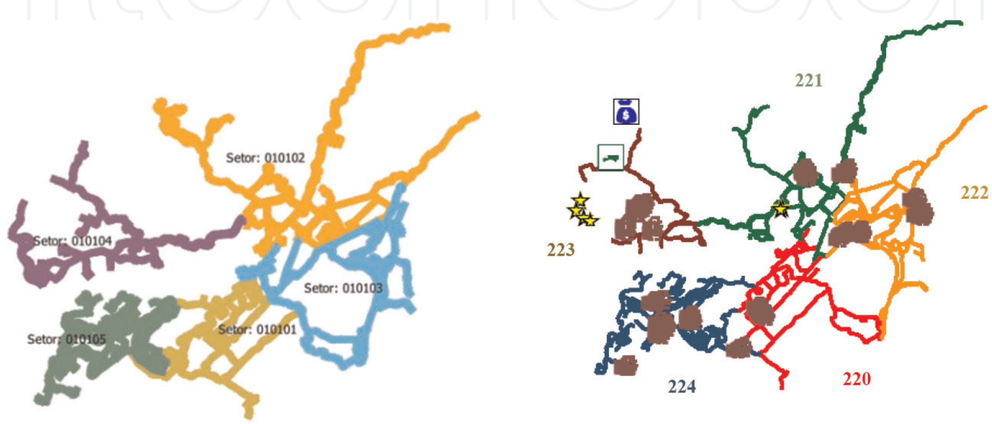

Figure 4.
Maps indicating the division of operation on Mondays in downtown Petrópolis-RJ, where on the left, we see the original five sectors (non-overlapping) and on the right, the final optimized sectors.

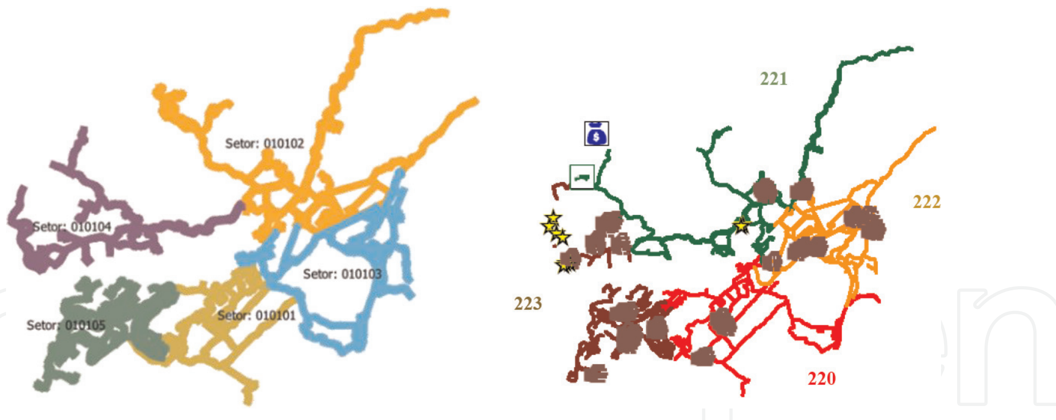

Figure 5.
Maps indicating the division of operation from Tuesdays to Saturdays in downtown Petrópolis-RJ, where on the left, we see the original five sectors (non-overlapping) and on the right, the final four optimized sectors for these days.

Figure 6.
Sector 220, high variability production between Mondays and Tuesday–Saturdays (more stable).

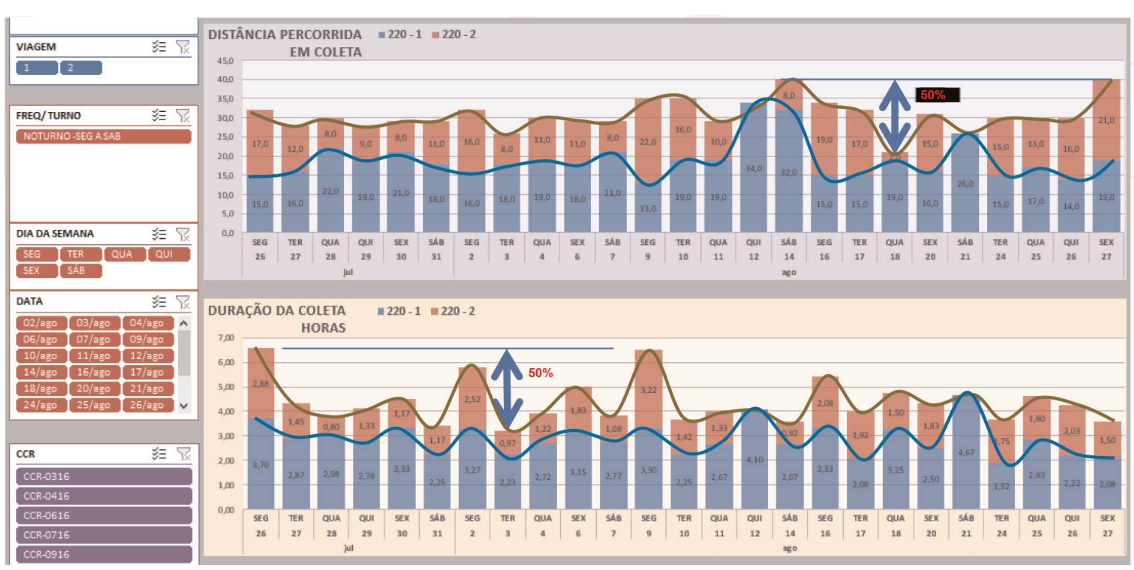

Figure 7.
Sector 220, above the variability between total distances traveled per trip (above) along the days of the week and variation in time duration (below) between Mondays and Tuesday–Saturdays.

the garbage (no sector overlapping) and minor changes between days of collection to warranty the monotonicity and completeness of the service.

Figure 3 presents the state of the planned sectors we found in downtown Petrópolis-RJ; they were covered daily at night. The sectors were planned considering overlapping coverage (**Figure 3** - left), meaning that it was no longer possible to precisely identify the places where the garbage came from. It was necessary to separate the groups to be unique and make the statistics of production (**Figure 4**-right).

Figure 4 presents the previous (left) and new sectors' (right) configurations for the new spatial division in reason of the optimization of the sectors and routing to be performed on Mondays. **Figure 6** presents the previous (left) and new sectors'(right) configurations for the new spatial division to be performed from Tuesdays to Saturdays with four vehicles only. It can be also seen in **Figures 4** and **5** that the collection is also performed in star points (containers, gas stations, bars, supermarkets, etc) and brown points (called "manual collection"—places where the vehicle cannot come in and/or traverse. It normally stops, and a collector take it manually hundreds of meters away from the parking point).

The practiced routes are performed following a great route between all street segments from garage to transfer station. It means that the driver follows the sequence defined by the great route, and every time the driver wants to discharge (in general because of the vehicle overload), he drives to the transfer station.

In **Figures 6** and **7**, we can see the great difference between the garbage production, distance, and time on collection for sector 220 by the city on Mondays (due to higher flow of commerce on this day) and the rest of the week. It achieves about 50% of the production between these days in downtown Petropolis-RJ, and it indicates that the service plans must be distinct for each period (Mon and Tue-Sat). For Tue-Sat, the dispersion of the garbage is very low.

Table 1 shows the scenario of the production practiced in each sector before the optimization. It is convenient to observe more precisely the variations between each sector on Monday.

Our field evaluations had been done in just one scenario, in case of the service movements realized for Tuesday–Saturday, because it may be extended for Monday, after adjusting the street coverage and special local constraints needed to be satisfied (one-way streets, passing more than once in particular streets, passing particular places in a specific time, manual collection, and others). The project identified all the turns and prohibitions during a period of 35 days.

After identifying unfeasible movements, many of them were lost because they were not properly identified. We prepared the drivers in the use and navigation of the CherryTrack®LIX for a week, and then we started evaluating the routes in the next week. We tried four times to run the plans in plain use. The first time, we evaluated the completion of the routes and use of CharryTrack® Lix by the drivers. Problems with the constraints (turns and prohibitions) and with the response of the app were detected that disturbed the execution of the routes, leaving many streets without coverage. On the second try, we had problems with changes in the field not being reported, vehicle overload before expected, and still matters with the app response. On the third try, we had problems with vehicle overload before expected and no more problems with the app response, and finally, on the fourth try, we only had problems with tire flat and no more, although a new change was necessary in the routes asked on the last day. The evaluations were done from October/2021 to January/2022.

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Sector					PRODUCTION			Km			HOURS			Bal	Discharge - t		
	Day	Trips	# Days	Total	Kg/Trip	Average (Kg)	Var %	Total	Ave	Var %	Total	Ave	Var %	Ave %	Indicated	Average	Var %
220	MON	8	4	66,334	9636.29	8291.63	8.11%	405	101.25	5.43%	32.58	8.15	5.16%	95.01%	7.92	8	0.95%
221	MON	8	4	68,546	10003.43	8568.14	8.38%	400	100.00	6.00%	30.17	7.54	3.78%	94.86%	9.95	10	0.45%
222	MON	10	4	76,132	11983.61	7613.19	28.70%	483	120.75	19.40%	34.03	8.51	12.97%	84.87%	8.91	9	1.03%
223	MON	11	4	79,595	10140.39	7235.89	20.07%	398	99.50	31.87%	36.40	9.10	20.87%	89.01%	6.96	7	0.61%
224	MON	2	2	13,621	8032.16	6810.11	8.97%	97	48.50	1.46%	10.53	5.27	34.91%	100.00%	10.79	11	1.93%
	MON	39	18	304,228	10001.56	<<– Ave Day/ Sector	20.65%	1783			143.72			92.75%			
	TUE-SAT	181	100	1,163,225	11632.25	<<– Ave Day/ Sector	7.79%	9195			651.03			89.52%		9.28	

Table 1.
Scenario of the production per sector for Monday and Tuesday–Saturday in downtown Petropolis' sectors.

4.1.1 Comparison between original situation and optimized scenario (Mondays)

The final solution obtained for Mondays is the one shown in **Table 2**.

As a result, we obtain the following if we consider the same number of days covered per sector (if we consider days: 16/08, 9/08, and 27/07):

- Little increase in total distance: before – 483 km, planned – 484 km (increase: 0.21%)
- Reduction in total route time duration: before – 124 h, planned –132 h (savings: 6.2%)
- Increase in balance between trips: before – 88.51%, planned – 94.23%

The difference in distance is because of the new constraints that are not practiced by the concessionaire are here considered in the final planned routes. The reduction is in fact because of the better-balanced routes take less time spent for collection in 6.15% as the plan established.

4.1.2 Comparison between original situation and optimized scenario (Tue-sat)

In the computation of the sectors and routes for daily night collection in downtown Petropolis/RJ, we needed to reconsider the previous collection sectors and the production statistics for Tuesdays-Saturdays. There were plenty of

Sector	Production-Kg	Distance (Km)	Time
220	48,176,64	286,155	26:18:30
221	50,391,69	307,491	26:32:00
222	49,657,23	351,486	25:15:12
223	45,394,77	185,598	19:38:09
224	47,907,27	321,246	26:01:36
Total:	241,527,6	1451,976	123:45:27

			DAILY NIGHT		
DAY	**DATE**	**Km**	**HOURS**	**PROD**	**BAL**
SEG	16/08/2021	505,00	46:40:00	86,726,64	80,99%
SEG	09/08/2021	491,00	43:36:00	78,242,52	90,77%
SEG	27/07/2021	453,00	41:36:00	75,077,97	93,75%
	Trips:	31			
	Total:	1449,00	131:52:00	240,047,14	

-0,62%	-0,21%	6,15%
Production	Km	Time

Table 2.
Solution obtained after all corrections in the field, to be applied to the sectors on Mondays at downtown Petropolis/RJ.

information for these cases, and we could build the routes with much greater success than before.

With the considerable decrease in the daily production between Mondays and the rest of the week as shown in **Figure 7**, the sectors were recalculated with the adequate parameters of production. We found a new configuration with four sectors. Running up the capacitated clustering according to the vehicle's technical capacity in the sectors to build the circuits, meaning each trip, as can be seen in **Figure 1c** and **d**, the solution achieved impressive savings in the first plan produced. Considering that many local constraints were not satisfied, we included them in the graph and obtained a new plan for the first execution in the field. As mentioned previously, the process continued until both constraint satisfaction and app return were in order; we tried four times, until the last, although still with problems with vehicle's breakdown, it meant that the completion was not compromised at all. **Table 3** shows the last result obtained, **Table 4** presents the plan produced by SisRot® LIX, and in **Table 5**, we present the estimated savings considering the numbers from production spreadsheets (92 trips, 27/07/21–29/01/22) with vehicles' breakdown during service and without this occurrence.

The savings achieved 17,86% with distance. The final plan also reduced 1 vehicle and 1 driver in 5 for both resources. We considered the effect of unemployment, and we maintained the same number of collectors, but it caused prejudice to the process, because the collection with three men was faster (9.54%) than a collection with four men. It means that on average a team with three men collects 2548.38 kg/h, while a team with four men collects 2326.36 kg/h in Petropolis/RJ. In **Table 6**, we can see the average efficiency (kg/man-h) of the collectors between sectors and days of the week to better understand this important variable in decision-making.

The experience with CherryTrack® LIX was fundamental in the process of establishing the sectors and routes in the field. After training drivers for a week, we had big problems with those who did not repass the training of studying the app at home. The only one who did it was successful in every route he did and always finalized his job before all. He was used as an example for the others, and three of them succeeded in the end. One more resistant did not want to use the technology and always avoided it. In the end, the supervisor and all drivers were fully integrated with the app and did not want to look at maps anymore. The possibility to control all the drivers anywhere, even driving a truck, was considered the most advantageous part of the app for the supervisor, and for the drivers, it was the route indication while in operation and the state of completeness of the service any time.

DAY	SECTORS					AVERAGE	
	220	221	222	223	224		
MON	917.07	1117.49	1078.38	869.83	1100.95	917.43	
TUE	922.14	913.80	1009.53	895.69	464.08	900.24	882.35
WED	846.94	988.05	1041.91	796.48	442.76	858.43	
THR	906.83	960.65	1043.30	848.87	442.66	893.46	
FRI	928.20	1030.42	927.28	780.95	558.33	839.28	
SAT	887.13	925.72	994.71	847.21	435.22	900.24	

Table 3.
Result of the application in the field, for the 4th revision plan to Tuesday–Saturday.

EXECUTED OPERATION- PETROPOLIS-FORÇA AMIBIENTAL - 01/29/22											
	Vehicle	**TARE**	**DRIVER**	**No Collectors**	**Tp**	**Weight**	**L**	**Kg/Km-h**	**Kg/hom-h**	**Total Time**	**Distance**
220	8656	11,270	IGOR	5	1	7540	67,20	45,50	245,69	4:55:00	55
	4G25	11,640	IGOR	5	2	8685		144,35	548,55	4:13:00	51
221	4G20	11,590	ANTONIO	4	1	4990	58,80	19,99	129,95	2:30:00	62
	4G20	11,590	ANTONIO	4	2	7170	29,40	40,63	253,94	4:17:00	52
222	4G16	11,510	ELCIO	5	1	7790	35,28	39,34	173,11	3:45:00	56
	8629	11,340	ELCIO	5	2						
223	8656	11,270	WALTER	4	1	5368	39,88	632,60	1581,51	7:30:00	113
	8656	11,270	WALTER	4	2	2610	100,80	15,92	91,53	4:32:00	54
						43,953	331,3621	134,05	432,04	42:00,0	443

Table 4.
The result of the 4th revision plan to Tuesday–Saturday (the time to complete the task is overestimated).

SECTORS							
Sector	**Trips**	**Crew**	**Weight (kg)**	**Bal%**	**Perimeter (m)**	**Km**	**Time**
220	2	4	16,863,59	97,90%	29,559,00	102.896	09:30
221	2	3	16,107,36	97,80%	35,726,00	102.417	10:17
222	2	4	16,552,51	99,47%	34,745,00	122.193	11:01
223	2	4	15,135,84	96,46%	27,064,00	104.909	09:00
			64,659,30	97,91%	127,094	432,42	39:49:00
				Coverage		**TUE-SAT (km)**	
Executed with no Breakdown				96,17%		506,32	
Proposed in 02/02/23				100%		432,41	
Savings:						14,59%	
				Coverage		**TUE-SAT (km)**	
Executed with no Breakdown				100%		526,46	
Proposed in 02/02/23				100%		432,41	
Savings:						17,86%	
CREW PROPOSED PLAN							
SECTOR						**TUE-SAT**	
220						1 M + 4C	
221						1 M + 3C	
222						1 M + 4C	
223						1 M + 4C	
224							

Table 5.
Result in savings considering service with and without vehicle breakdown.

Types of vehicle speeds	Speed (km/h)
Empty	45
Full	35
In collection	5
Deadheading	17

Table 6.
Speeds of operation considered in the project for the city.

We applied the same SARP methodology explained above in domiciliary waste collection to other Brazilian cities like Franca/SP, Campo Grande/MS, Mazagão/AP, and Búzios/RJ with success, obtaining 12–28% savings in the total distance traveled and from 5 to 9% savings in the staff's working hours. The relevance of the methodology opened new opportunities to make the waste collection more predictable and less susceptible to the variations of the load per day.

4.2 Selective waste collection

We developed a project in June 2018 for domiciliary selective waste collection for the city of Bom Jesus dos Perdões – SP. The city's population is estimated to be 24 mil inhabitants [32], and it is a small and winter/summer town. The project was specific to generating sectors and routes, and their schedule was for periods of one week, for a contractor [33] of the local selective collection association. The contractor implemented a new recycling plant for the association, with the support of the best Brazilian knowledge in recycling tools and operational management. Here we detail how we developed this project.

The geographical data set came from OSM (Open Street Map), Google Maps™, and Bing™, and it were adjusted with QGIS 2.18 to be completely legible and useable for sector-arc routing. The data from population density and distribution along the municipality were obtained from the "Setores Censitários, IBGE" [34].

The work consisted of creating sectors and collection circuits from the collection area, **Figure 8**, and studying a better place to install the recycling plant (Distrito Industrial or in the Transfer Station), respecting the data provided by the contractor. The sectors and routes were divided into three geographic levels of grouping areas (regional, zones, sectors, and circuits) and thus named (Regional: 01; Zones: 01..05; Sectors: 01..04; Circuits: 01.. 04). This method allows the total route of the vehicle to carry out the selective collection to reach the shortest/fastest possible length while at the same time allowing the most adequate execution and inspection on the field.

A sector in the domiciliary selective collection has the same definition as in the household refuse collection, and the trips represent the circuits. The basic difference is that the trips are composed of lighter loads, and the vehicles used are not compactors. The garbage is measured in volume, and it is disposed of in a way to be separated manually faster. The garage and the recycling plant were running in different places; the garage were in the Distrito Industrial but for the project evaluation it could also be considered in the same location of the recycling plant, as can be seen in **Figure 8**.

The plans considered operational speeds, as exposed in **Table 6**, where these values were obtained from other experiences in a city with same features. Basically, it is the defined speed while vehicles are empty, in the collection, deadheading (traversing between two collection points without service), and in full charge or going to the recycling plant.

The effort of the drivers was considered, as proposed by McBridge [35] and Bodin et al. [36], to reduce "U" turns in arc-routing route calculations (**Table 7**); we used the

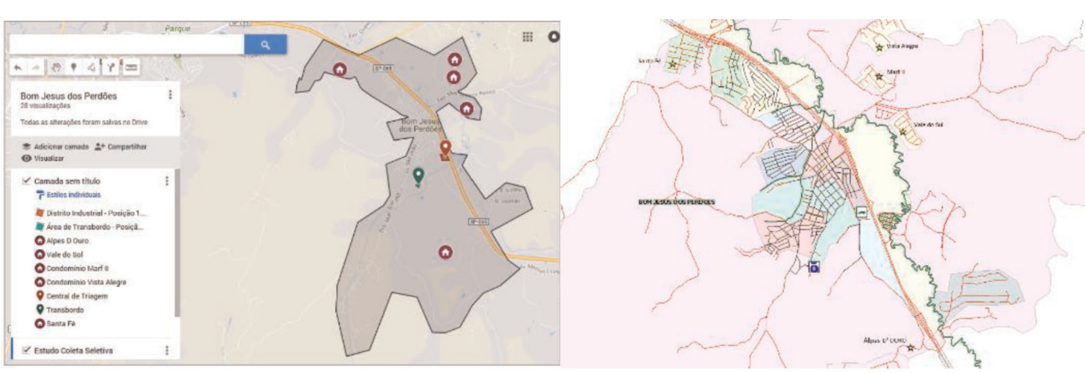


Figure 8.
Maps of the selective collection situation in the city of Bom Jesus dos Perdões on Google maps™ and SisRot LIX®.

Maneuver	Effort measure
Straight on	1
Turn left	10
Turn right	25
U turn	100
Service in adjacent links	Add 0 to the effort
Alternate service and no service in adjacent links	Add 5 to the effort
No service in adjacent links	Add 10 to the effort

Table 7.
Measures of steering effort in route movements.

approximative line-graph methods proposed by Negreiros & Palhano [37] to reduce the effort on maneuvers.

The workload was set to be 8:00 with an interruption of 1 h for lunch, as per the regular Brazilian labor laws. On tough days, like Mondays, when the garbage is of higher load than the rest of the week, there is a necessity of extra labor time; the association regulates this once all the people are in cooperation. The discharge time was defined to be 20 min because, in this case, there was a necessity for other people to come and help discharge manually the incoming vehicles.

The parameters related to the production of recycling were: 1 kg/inhab, where 30% were recycled with 55% of it recovered, totalizing 0.165 kg/day-inhab of recycled available (1 kg × 0.3 × 0.55). The collection would be performed by one vehicle with 28 m^3 of maximal occupation and 95% (26.6 m^3) – a surcharge of 20% is admissible. The admitted ratio between production and volume was 36 kg/m^3. The load collected by the vehicle per trip was 28m^3 or 957.6 kg (28 m^3 × 36 kg × 0.95) or at most 1200 kg or little more (±5%) in cases of possible seasonality.

- The city has four condominiums: Alpes D'Ouro, Vale do Sol, Vista Alegre, Santa Fé and Marf II, where the waste is more frequent on weekends and holidays. For them, it is admissible that the vehicle can carry kg.

The sectors were created to be covered one day a week from Monday to Friday. As can be seen in **Figure 8**, the polygon returns:

- The collection area: delimited by the polygon in gray.

- Recycling plant: where the vehicle may discharge.

The street network was identified, as in **Table 8**:

Street segments	Total	Street segments requiring service	Total collection perimeter (m)	Estimated total weight/volume total per week (−20%)
Doble way	403	124	63.353	37,936 kg
One way	4327	931		1354,86 m^3

Table 8.
Numerical data of the network and waste production estimates.

4.2.1 Census sectors', occupation, and production of the streets

Census sectors are defined by georeferenced polygons, where a census taker performs his survey task in the demographic census every ten years. The publicly available information informs a digital cartography of the number of households and residents in the inner region of the polygon that represents it. Using geoprocessing, the production of waste in each census sector is found by multiplying the number of people by the estimated production of selective waste per person per day of collection (0.165 kg/day of collection). By doing so, the perimeter of the street network considers only the places where the truck must pass (required street network) and receive the garbage distribution for each street segment, thus transforming the garbage in kg/m in the required graph. In the example in **Figure 9**, the required graph is weighted with 0.165 kg/person × 603 people = 102.79 kg, and given that this required graph perimeter is 1821 m, then we find 0.056 kg/m to distribute among the 1821 m of required connections of the set.

4.2.2 Collection zones

Table 9 presents the numerical data referring to the collection zones built with SisRot® Lix. **Figure 10** shows a geographical representation of the division of selective collection zones for better visualization. It is understood that this final configuration is the most appropriate, as it allows for better contiguity and adequate compaction, given the presence of the D Pedro I road, or Marginal Bom Jesus, separating the municipality into two large regions. It can be seen in **Figure 9** that to the north, the Vista Alegre condominium exceeds the city limits, causing an unfavorable impact on the calculation of routes in this zone.

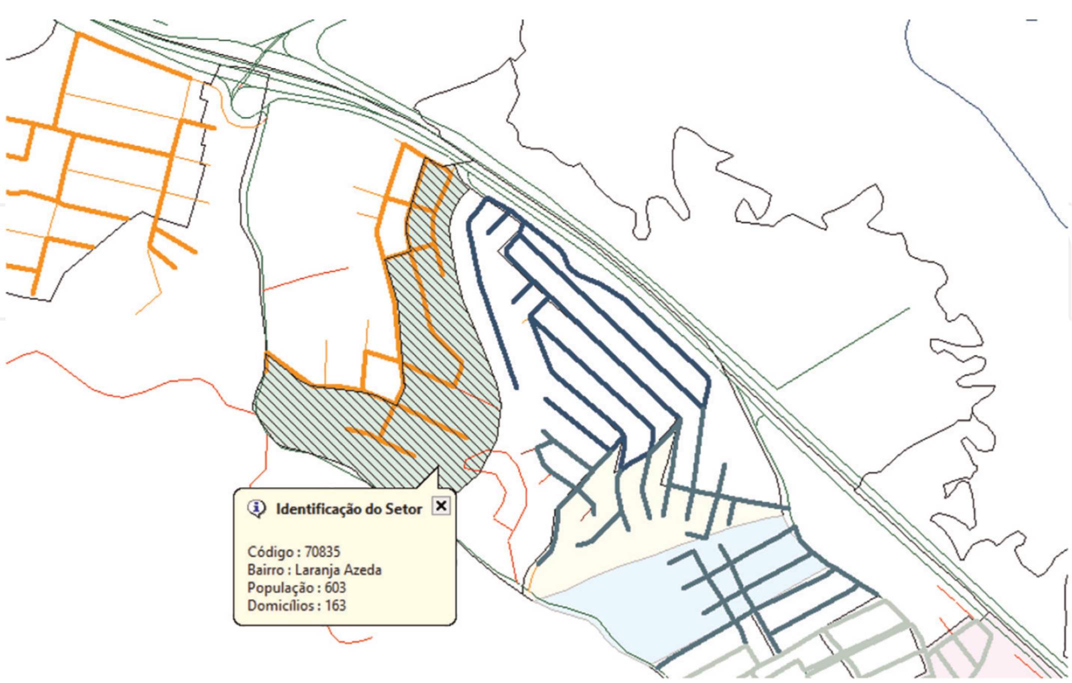


Figure 9.
Census sector, reproduced from the digital base of the IBGE census sector mesh (IBGE, 2016) of the city of BJ dos Perdões/SP by SisRot® LIX. The required road network (in darker yellow) that is within the sector receives the production of the corrected population of the sector.

ZONES	No. street segments	Perimeter (m)	Production (kg)	Volume (m^3)	Sectors	Circuits	Vehicle (kg)
101	271	14,880	7940.9	220.58	2	8	1000
102	233	13,722	5663.18	157.31	2	6	1000
103	119	9072	8711.05	241.97	2	8	1000
104	240	20,612	7897.31	219.37	2	8	1000
105	191	12,687	7699.31	213.87	2	8	1000
Total (5)	1054	70,973	37911.76	1053.10	10	38	

Table 9.
Numerical construction details of the zones, with information on the required street segments.

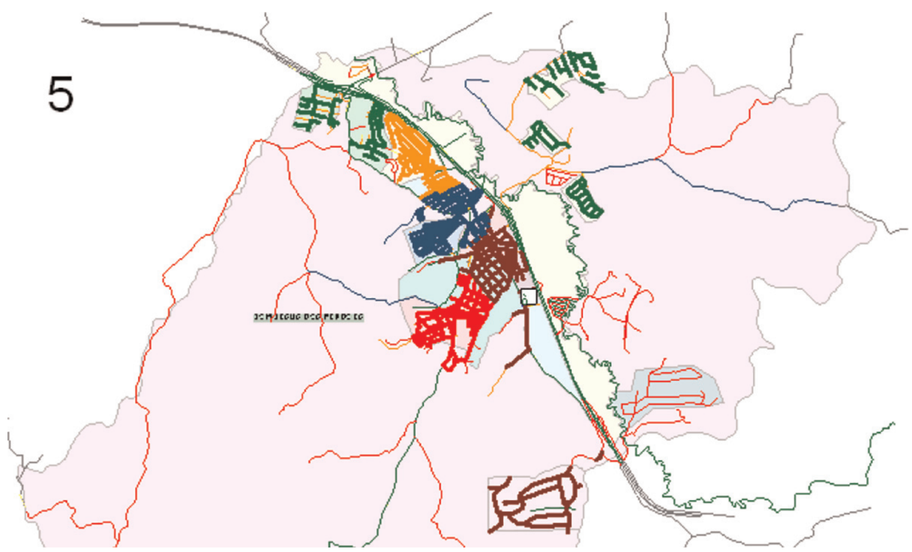


Figure 10.
Map containing the division of the clusters of selective collection zones for the city of BJ dos Perdões.

4.2.3 Collection sectors

Table 10 presents numerical data referring to the collection sectors built with SisRot® Lix. **Figure 11** shows a geographical representation of the division of selective collection sectors for better visualization. This final configuration is the most suitable for the context of the local knowledge that has been made available. The dispersion of contiguous areas is noted in **Figure 11**, but all represent the same collection context, mainly in the condominiums to the northeast of the city (Vista Alegre, Marf II, and Vale do Sul).

4.2.4 Collection circuits

We finally arrive at the division of collection circuits. At this stage, it is necessary to guarantee the maximum contiguity between the circuits to compose the collection sectors and hence allow the creation of routes with the best operational results. **Figure 12** shows a geographical representation of the division of selective collection circuits for better visualization. This final configuration is best suited to the context of

Sectors	No street segments	Perimeter (m)	Production (kg)	Volume (m^3)	Circuits
10,101	136	6244	4006,6	111.2944	4
10,102	135	8636	3934,3	109.2861	4
10,201	78	6056	2623,18	72.8661	4
10,202	155	7666	3040	84.4444	3
10,301	43	4200	4421,88	122.8300	3
10,302	76	4872	4289,18	119.1439	4
10,401	136	13,219	3929,46	109.1517	4
10,402	104	7393	3967,85	110.2181	4
10,501	99	6948	4048,88	112.4689	4
10,502	92	5739	3650,43	101.4008	4
Total (9)	918	64,729	33,905,16	1053.1040	38

Table 10.
Numerical data of the selective collection sectors projected for BJ dos Perdões.

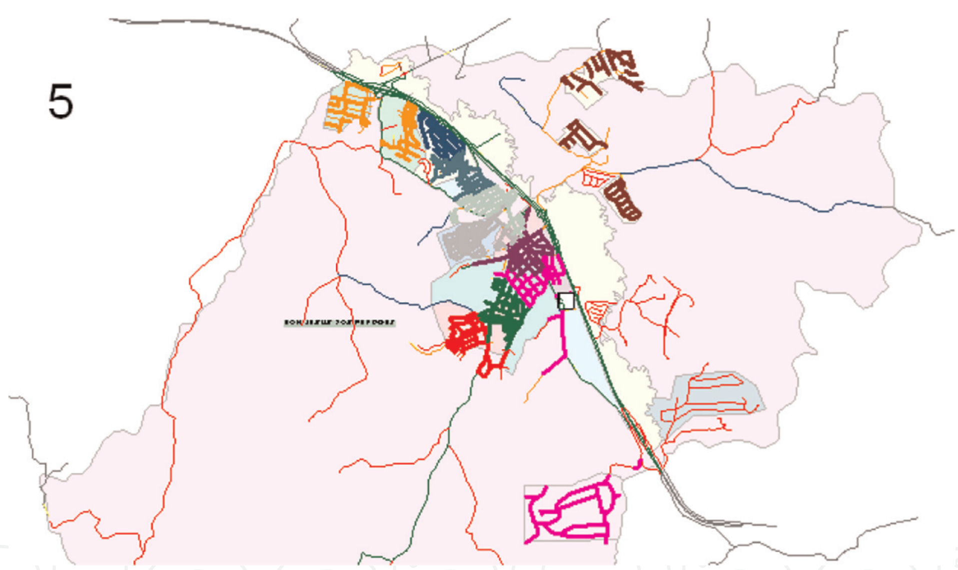


Figure 11.
Map with the division of sectors in the city of BJ dos Perdões.

the local knowledge that has been made available. Note in **Figure 12** the dispersion of contiguous areas further to the northeast (in condominiums).

Table 11 presents the numerical data referring to the collection circuits built with SisRot® Lix. Note that the nominal values allowed for each circuit were exceeded considering the maximum volume of the vehicle trunk of 26 m^3. At first, it should be considered that the updated IBGE data indicate 20% more in the population that was passed to this study; in addition, the seasonality of the places in overload brought the need to maintain the structure in this way. It is recommended that these areas be observed during the implementation phase of the routes, as there are no reliable data for this sizing.

The solutions presented in **Table 11** consider the following nomenclature:

Circuit: is the identifying label of the circuit (Reginal, Zone, Sector, Circuit);

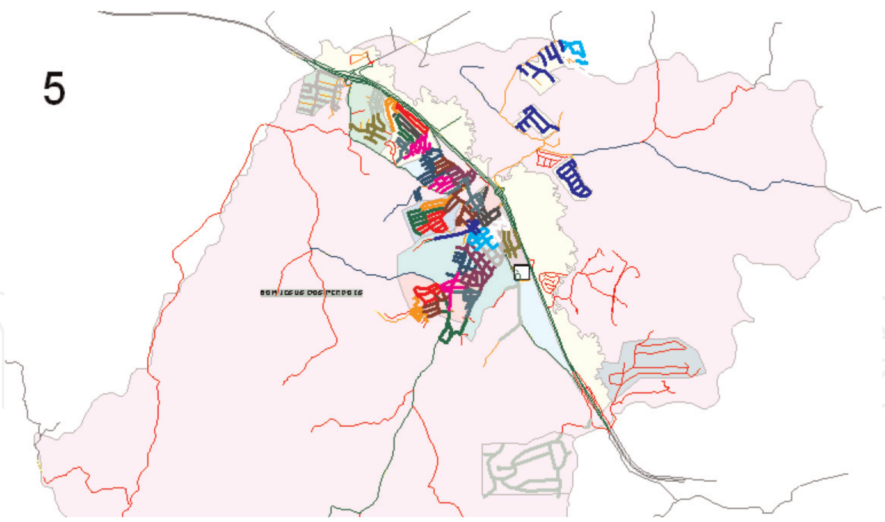


Figure 12.
Visualization of the distribution of the collection circuits designed for BJ dos Perdões.

SSeg: Number of street segments in the sector;
Perimeter: is the total length of the required street segments of a circuit;
Prod: is the estimated production (in kg) of the circuit;
CDist: is the distance that the vehicle would travel per trip;
CTime: is the time spent on the trip;
Bal: is the rate between trips in the sector – Bal = $\left(\frac{\sum_{i=1}^{nv} Prod_i}{nv * \max\{i=1,..,nv: Prod_i\}}\right)$;
Load: is the estimated total load collected in the sector;
Time: is the estimated total travel time in the sector (hh:mm:ss);
Km: is the total distance traveled in the sector (in km);
Vehicle: is the maximum capacity—in kg (−20%)—of the reference vehicle.

4.2.5 Routes of collection circuits

All the circuits clustered were calculated for both final destinations in evaluation (Distrito Industrial and Transfer Station); these two places already have the basic infrastructure to install the recycling plant, and it was necessary to define the best solution obtained with routes and time between both. The result presented in **Table 11** refers to the installation of the plant in Distrito Industrial; the variable cost gained with this installation was 16.5% better than if it was installed in the Transfer Station.

An example of the multigraph of the routes directly extracted from SisRot®Lix can be seen in **Figure 13**. The use of the generalized sector-arc-routing solver that joins node and arc routing in the same context of decision-making is shown.

4.2.6 Sectors' schedule

Only one vehicle and one crew (driver and three collectors) will be needed to carry out the work of the entire city. The scale of the vehicle and crew, as shown in **Table 11**, indicates that the sector that covers the Alpes D'Ouro condominium (Sector: 010401) should be visited on Wednesday afternoon, since it is not possible to serve all the condominiums on the same day as required by RECICLEIROS. The Santa Fé

Circuits	SSeg	Perimeter	Prod (kg)	Vehicle	CDist.(km)	CTime	Sector	BAL %	Km	Time	Schedule	
1,010,101	32	1836	959,13	1200	6.019	01:02:17	10,101	93,54%	23,56	3:58:34	Morning	MON
1,010,102	49	1871	947,75	1200	5.766	01:01:27						
1,010,103	33	1353	1070,87	1200	6.546	01:01:08						
1,010,104	22	1184	1028,86	1200	5.224	00:53:42						
1,010,201	30	2113	1231,09	1200	5.242	00:59:43	10,102	79,89%	20,53	3:59:13	Afternoon	
1,010,202	45	2409	910,37	1200	5.470	01:03:07						
1,010,203	31	1979	1030,62	1200	5.378	00:59:48						
1,010,204	29	2135	762,22	1200	4.438	00:56:35						
1,020,101	28	2849	936,21	1200	14.431	01:49:13	10,201	91,34%	33.861	4:27:28	Morning	TUE
1,020,102	25	1424	729,71	1200	9.386	01:16:19						
1,020,103	25	1783	957,27	1200	10.044	01:21:56						
1,020,201	13	573	1119,07	1200	12.030	01:23:28	10,202	90,52%	44.186	5:22:38	Afternoon	
1,020,202	34	1116	1119,5	1200	12.371	01:29:04						
1,020,203	108	5977	801,42	1200	19.785	02:30:06						
1,030,101	12	1157	1066,93	1200	7.149	01:03:32	10,301	82,78%	29,79	4:17:28	Morning	WED
1,030,102	11	1369	837,31	1200	6.924	01:04:28						
1,030,103	9	811	1182,16	1200	7.344	01:02:19						
1,030,104	11	863	1335,48	1200	8.377	01:07:09						
1,030,201	15	1100	1233,79	1200	5.546	00:54:58	10,302	86,91%	27,14	4:05:53	Afternoon	
1,030,202	26	1661	1175,09	1200	7.120	01:06:02						
1,030,203	15	789	1006,29	1200	6.651	00:58:29						
1,030,204	20	1322	874,01	1200	7.821	01:06:24						

Circuits	SSeg	Perimeter	Prod (kg)	Vehicle	CDist.(km)	CTime	Sector	BAL %	Km	Time	Schedule	
1,040,101	23	2141	952,97	1200	4.345	00:55:35	10,401	92,32%	28,33	4:57:47	Morning	THU
1,040,102	21	1758	940,27	1200	3.562	00:49:25						
1,040,103	77	7770	972,14	1200	16.992	02:26:29						
1,040,104	15	1550	1064,09	1200	3.429	00:46:18						
1,040,201	18	1646	1067,05	1200	3.751	00:49:05	10,402	92,96%	18,97	3:39:56	Afternoon	
1,040,202	28	2182	914,29	1200	4.825	00:57:42						
1,040,203	29	1554	994,47	1200	4.655	00:52:58						
1,040,204	29	2011	992,04	1200	5.741	01:00:11						
1,050,101	29	2198	975,59	1200	5.801	01:04:05	10,501	95,37%	21,25	3:53:27	Morning	FRI
1,050,102	17	1672	983,66	1200	5.699	01:00:05						
1,050,103	14	957	1028,31	1200	4.468	00:48:59						
1,050,104	39	2121	1061,32	1200	5.283	01:00:18						
1,050,201	21	1216	842,96	1200	6.356	00:59:04	10,502	82,83%	22,01	3:47:18	Afternoon	
1,050,202	24	1827	833,2	1200	4.908	00:56:27						
1,050,203	22	1248	872,43	1200	5.441	00:55:37						
1,050,204	25	1448	1101,85	1200	5.301	00:56:10						
Total (38)	1054	70,973	37,911,76		269.619	42:30:01						

Table 11.
Collection circuits and sector results, showing the final numbers with routes and schedule of one vehicle during the week.

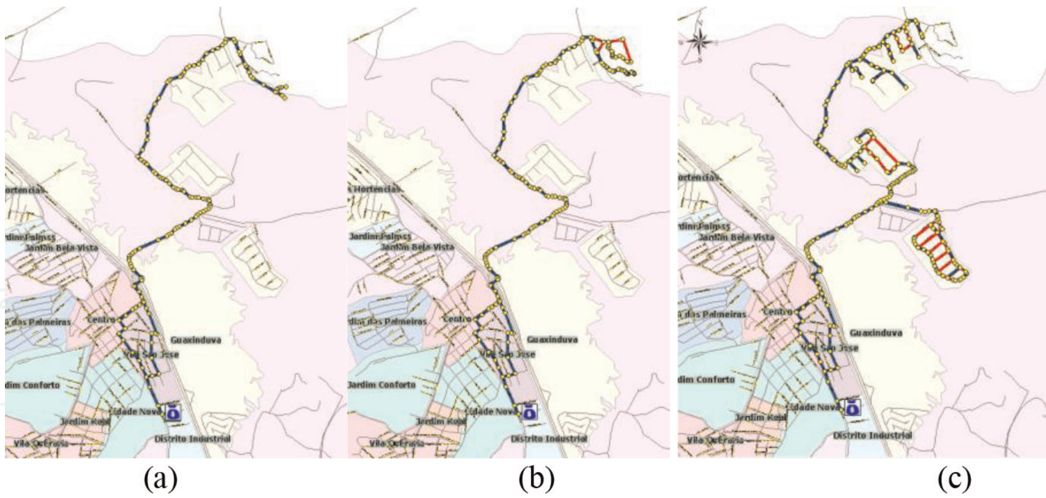


Figure 13.
Routes for sector 10,102 - (a) route for circuit 1,010,201, (b) route for circuit 1,010,202, and (c) route for circuit 1,010,203.

condominium (Sector: 010201), while the Vista Alegre, Marf II, and Vila do Sol condominiums (Sector: 010202) must be covered on Tuesdays as required by the association. In this way, operations are as close to Tuesday as possible. Friday had zone 0105 with the highest service load; however, it can be changed by moving the service of zone 0105 to Thursday or zone 0101 to Monday.

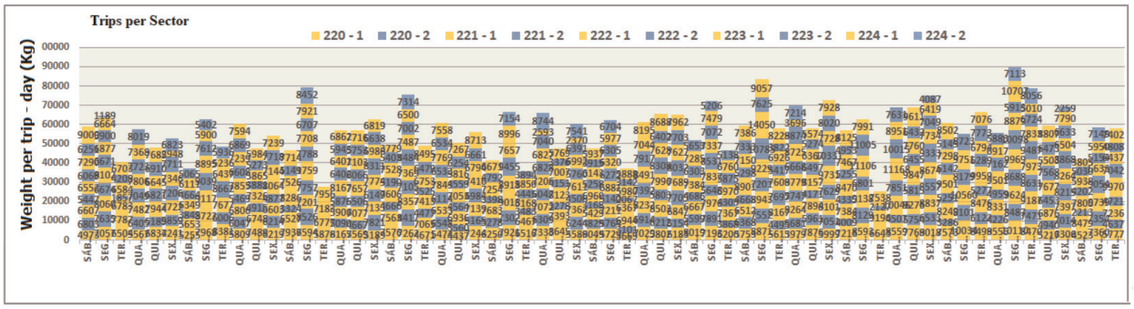
Alternative scales can be made, as a discharge time of 20 minutes was considered, and this can be reduced over time.

5. The effect of savings in domiciliary waste collection

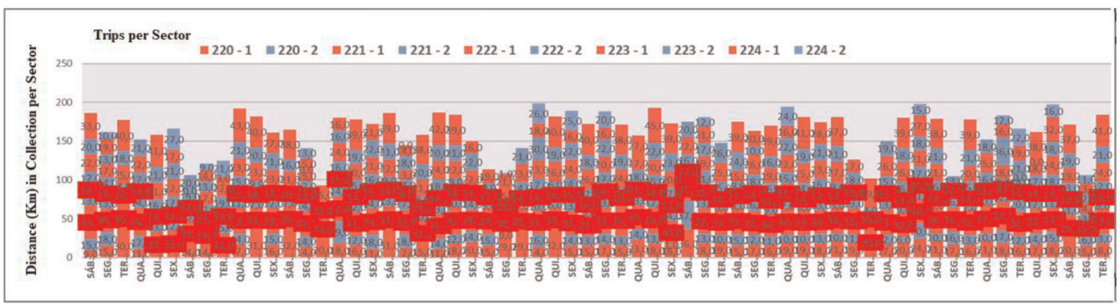
Using as parameter the spreadsheets of costs publicly available in Brazilian municipality bids, there are mainly two centers of costs considered: staff and vehicle (or equipment). In the staff spreadsheets, the costs consider labor hour, unsanitary, extra time (day or night), working hours on holidays (day or night), vacation, food and transportation, termination, and social security according to the category's municipal syndicate rates. For the vehicle or the equipment spreadsheets, the costs consider maintenance and fixed costs, tires and tubes, lubrication and washing, average costs of vehicle consumption per km or per hour in operation while stopped, depreciation, annual license, insurance, and, finally, the percentage of the invested capital to have the vehicle if it is included. All these are composed in a final cost, which is approximately 60% consumed by the staff and 40% by the vehicle and/or equipment used. Depending on the value of the fossil fuel (diesel) used and distance traveled by the fleet, this difference can be lower, but it also suffers from syndicate annual intervention on the labor costs of collection.

Figure 14 presents the behavior of waste collection in downtown Petrópolis/RJ, where (a) presents the loading per day and (b) presents the distance traveled collecting in the sectors that are covered from Monday–Saturday at night with an 8.2-ton compactor and three garis per vehicle.

In sector routing, the major impact on savings is in the reduction of the number of sectors, meaning fewer vehicles used, and in the total distance traveled. In our evaluations in the field, we also found an expressive reduction in the staff for domiciliary waste collection. Although it was indicated in Plan A that it is better to use four men



(a)



(b)

Figure 14.
Domiciliary waste collection in downtown Petrópolis/RJ. (a) Load per day – Downtown Petropolis/RJ. (b) Distance travelled per day – Downtown Petrópolis/RJ.

instead of three on daily-night collection in downtown Petrópolis/RJ, the global savings can be confirmed with our work of 7.52%. But, if the concessionaire wanted to use three men on Tue-Sat instead of four, it could bring a result in global costs savings of 14.04% (**Table 12**).

Table 12 presents an approximation of the global expenses with the vehicles and staff for the actual execution in comparison with Plan A and Plan B. These expenses depend on the costs according to the labor laws and the costs of maintenance of the vehicles, including expenses with fuel, tires, and so on. We did not include the costs of a vehicle, because the remained vehicle will be operated on Mondays in any case.

Considering the global costs (fixed and variable) of absorbing the sector-routing technology, as in **Table 12**, the results we obtained can be considered in the graphics exposed in **Figures 15** and **16**. The figures present three parts of bars corresponding to the costs of investing in the technology presented in this manuscript - project to revise sectors and routes of the city; for the amortization cost, the interest rate was set to

COSTS FOR PETROPOLIS/RJ (× R$ 1000,00)								
	Executed		**Plan A**		**Plan B**		**SAV A**	**SAV B**
Staff	R$ 132,13	59,50%	R$ 126,67	61,68%	R$ 112,19	58,77%	−4,13%	−15,09%
Vehicles	R$ 89,95	40,50%	R$ 78,70	38,32%	R$ 78,70	41,23%	−12,51%	−12,51%
	R$ 222,08		R$ 205,37		R$ 190,89		7,52%	14,04%

Table 12.
Global savings including all the real costs with staff and vehicles spences.

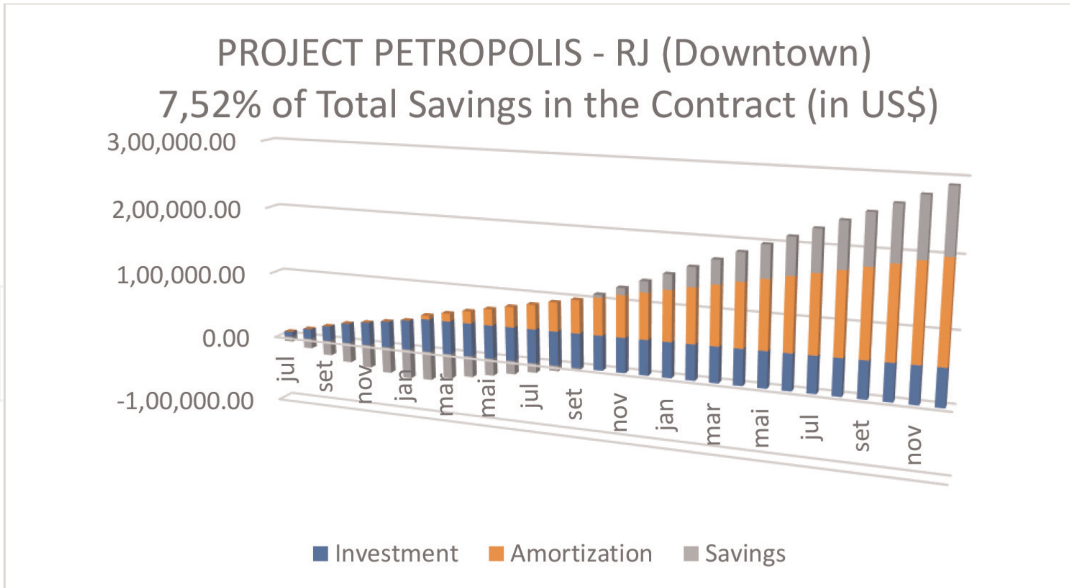


Figure 15.
Recovering investment when considering the team of collectors of plan a, returns start 15 months after project's end (may/2024).

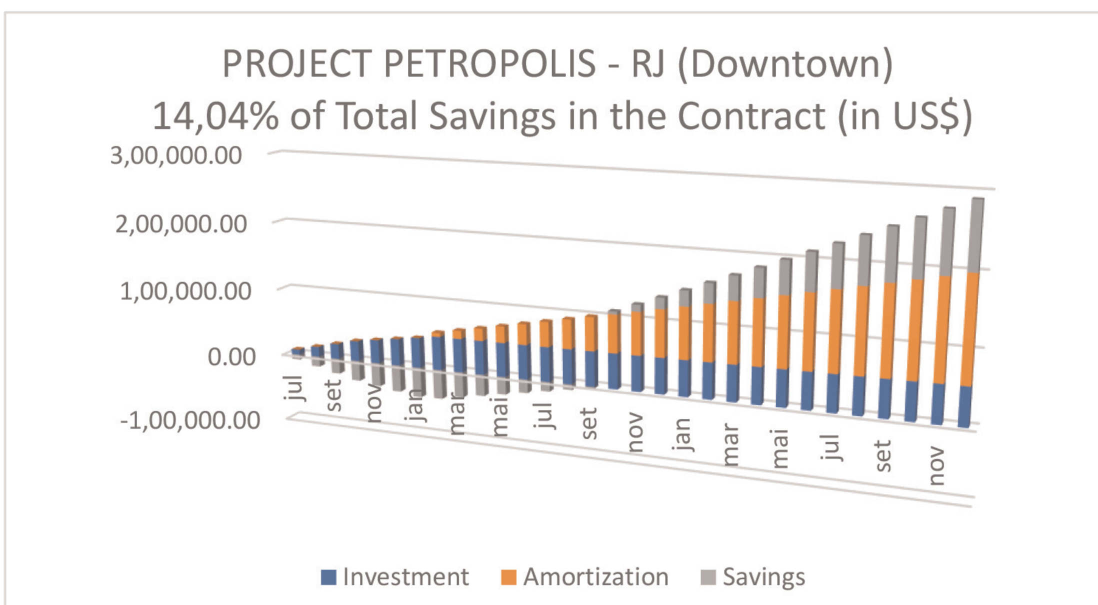


Figure 16.
Recovering investment when considering the team of collectors of plan B, returns start in Oct/2023, 9 months after project's end.

0.5% per month, and a 12% overprice in collection expenses from December to February, because of the rainy season and tourism overflow in downtown. For last the savings obtained with the results of the application.

The project returns the savings as the sectors and routes are implemented by the concessionary in the city; it starts returning as it starts to run. The breakeven point with the investment occurs in the 15th month from the beginning of the project for 7.52% of savings over spends in operational costs if Plan A is adopted (**Figure 15**). The breakeven point between savings and investment is reduced to the 9th month if the savings are of 14.04% (**Figure 16**).

6. Conclusion

The circuits generated and executed from October 2021 to January 2022 in downtown Petrópolis/RJ provided a reduction of over 17% in the total distance traveled by the fleet. It demonstrates that the plans generated by the framework can be executed with no differences between the planned and the executed results.

Regarding the cost of collector working hours, the average savings of 5% is relevant because the same work was performed with nearly the same amount of man-hours while covering 17% less distance, therefore increasing productivity. The savings with fixed and variable costs of over 17% were considerable, primarily because one driver, a crew (three men), and a vehicle were removed from the operation, eliminating their associated costs.

Another important aspect of the framework was the use of the CherryTrack® LIX Driver and CherryTrack® LIX Manager applications. The CherryTrack® LIX Driver, installed on a mobile device inside the load packer, assisted in navigation by indicating to the driver the sequence of roads he should follow to comply with the optimized route. Drivers were thought to have to "decorate" the route as the service execution relies on them. Embellish, CherryTrack® LIX broke this paradigm, which has dominated the medium for years. CherryTrack® LIX Manager allowed researchers, managers, and inspectors to monitor the service execution for each vehicle or the entire operation in real-time.

The project developed for RECICLEIROS in Bom Jesus dos Perdões/SP exceeded expectations. The new methodology can bring a better decision on recycling plant placement, and reasonable routes were designed and scheduled considering local constraints not fulfilled by the system but using manager reasoning.

OPILM SisRot® LIX, through its algorithms and software, reduced the operational costs of domiciliary waste collection in Petrópolis/RJ. The proposed SARP-based can be used for favorable tactical, operational, and strategic planning in waste management with success in other cities.

Acknowledgements

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Conflict of interest

The authors declare no conflict of interest.

Nomenclature

DSS	Decision Support System
SDSS	Spatial Decision Support System
OPILM	Optimized Planning and Integrated Logistics Management
GIS	Geographical Information System

GBMS	Graph Based Modeling System
ARP	Arc Routing Problem
CCP	Chinese Postman Problem
RPP	Rural Postman Problem
MRPP	Mixed Rural Postman Problem
CARP	Capacitated Arc Routing Problem
SARP	Sector Arc Routing Problem
ERP	Enterprise Resource Processing
WGIS	Web Geographical Information System
GPS	Global Positioning System
GPRS	General Packet Radio Service
RFID	Radio Frequency Identification
SQL	Structured Query Language
SisRot®LIX	Framework of SARP, GBMS and GIS systems
SisRot®FULL	Framework of VRP, GBMS and GIS systems
CherryTrack®LIX	Mobile Application to waste collection
VRP	Vehicle Routing Problems (Node Routing)
VPS	Virtual Private Server

A. Appendix

We show in more detail figures revealing more functionalities of CherryTrack®Lix with the apps Driver and Manager that was applied in the city of Petrópolis/RJ.

CherryTrack® Lix in operation.

We finalize with **Figures 17** and **18** showing the app CherryTrack®Lix in operation. In **Figure 17**, we have the best mounting of the smartphone in the vehicle cabin to help driver while in the trip. The app shows the next three blocks' movements while in collection and the next path between two distant collections, guiding the driver in the task of collection or just deadheading. In **Figure 18**, the manager version is shown; (a) shows to the supervisor the places where the collection must be done; (b) shows for a circuit of a selected sector the coverage of the circuit, while in red are the

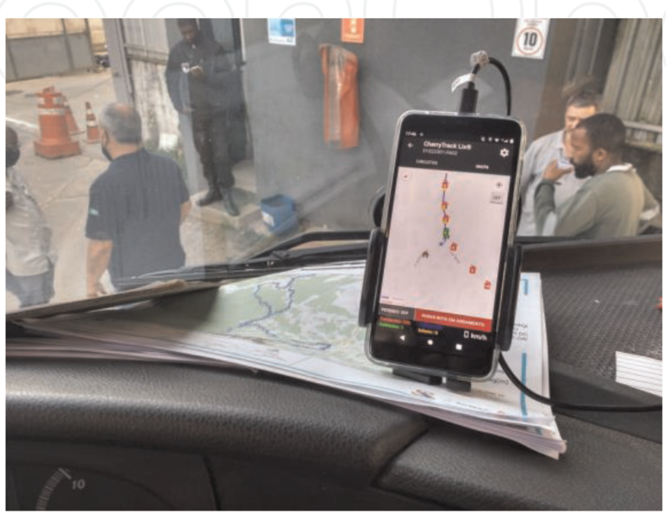
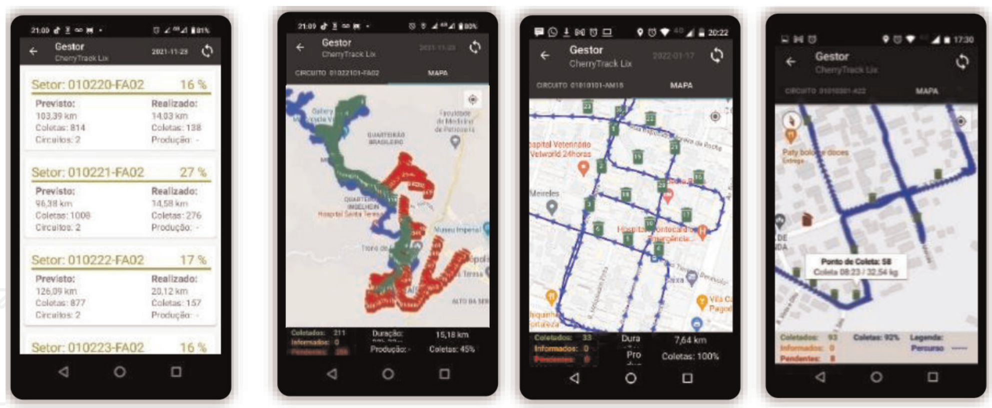


Figure 17.
Position of the CherryTrack® lix driver in the vehicle, including maps of the region of domiciliary waste collection.



(a) (b) (c) (d)

Figure 18.
New visualization of CherryTrack® lix manager, including maps of the region covered and left to be covered in the same trip of domiciliary waste collection.

non-collected street segment and in green are the collected segment; (c) the detailed movement performed by the driver in collection can be seen; and finally (d) reveals the load of collection obtained for each street segment in the path.

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