An exact method and Heuristic algorithms for single source capacitated facility location problems

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Abstract. In this article, it is described the process to solve the Single Source Capacitated Facility Location Problem, with an implementation for Heuristic, Metaheuristic and an Exact method. The SSCFLP Problem is focused on satisfying the clients demand with facilities, considering a set of possible locations for opening facilities. The objective is to minimize the cost of associating the clients with facilities, ensuring that all clients are served by only one facility without exceeding the capacity of the facilities.
To solve the following problem, formatted instances of Delmaire, Holmberg, OR, Yang and TBED1 were used. In order to assure this goal, 440 instances of the problem were provided, divided into 16 sets, along with the respective optimal solutions. Computational results are presented, which shows similar solutions in reasonable computing time when compared to other approaches.
At the end of the execution of each of the different methods, the necessary times were extracted as well as the gap with the optimal solution and comparisons were performed.

1 Introduction

1.1 Framework

As part of the Simulation and Optimization Curricular Unit (SO), inserted in the 1st year of the Master's Degree in Computer Engineering at the Escola Superior de Tecnologia e Gestão, taught by Professor Óscar Oliveira. We elaborated the following article having as main objective the application of knowledge in the exact resolution of combinatorial optimization problems.

The goal of this article is the resolution of the Single Source Capacitated Facility Location Problem for an Constructive heuristic, Constructive metaheuristic method and an Exact-Method. For the constructive heuristic solution, it was used a local search algorithm (shift or swap). For the Constructive Metaheuristic solution, it was used a GRASP approach to initialize the result set and then improve it using a local search algorithm.

At the end of the execution of each of the different methods, the necessary times were extracted as well as the gap with the optimal solution and comparisons were performed and the process of creating Excel files with this information was automated.

1.2 Case Study

Initially, it was possible to choose the Single Source Capacitated Facility Location Problem (SSCFLP), or the Two-Stage Capacitated Facility Location Problem (TSCFLP). The main difference between the two problems concerns the transport of the product, since in the second problem it makes a stop at the warehouses before reaching the customer. In the present work, the SSCFLP was chosen, since it had a wider literature and was the same problem chosen for the Exact Method algorithm. To solve the SSCFLP, we implemented three algorithms, one with heuristic method and two with metaheuristic method and an Exact Method. For the heuristic method, it was developed a local search algorithm with both shift and swap approaches. For both metaheuristic method, it was first initialized using a GRASP approach. In the first metaheuristic method, was also used a local search using a shift approach, and for the second developed metaheuristic method it was also used a local search using swap.

Exact methods, such as OR-Tools, allow us to arrive at the optimal solution, but require a high computational capacity, even for small instances.

On the other hand, the use of Heuristic Methods does not guarantee obtaining the optimal solution, however they are much faster and easier to implement. These Methods can be Constructive, Local Search or Metaheuristic.

2 State-of-Art

SSCFLP has various applications in numerous fields, such as supply chain management, distribution and logistics, healthcare or even urban planning [4] [7] [8] . There are lots of approaches to the SSCFLP, where all have the same objective, minimizing the costs of assigning clients to facilities while ensuring that each client is served only by one facility and the facility doesn't exceed it's capacity.

Rönnqvist et al. [8] proposed a repeated matching algorithm which essentially solves a series of matching problems until certain convergence criteria are satisfied. This method generated feasible solutions in each iteration in contrast to Lagrangean heuristics.

Guastaroba and Speranza [5], extended the Kernel Search heuristic framework to the SSCFLP. This heuristic involves solving a series of smaller optimization problems that only consider a subset of the decision variables, with the aim of finding an optimal solution for the overall problem. This heuristic outperforms most of the algorithms available in the literature, as stated by the authors.

The corridor method, is a algorithm proposed by Caserta & Voss [1], where Lagrangean relaxation is used to find potential solutions to a problem. Then, it creates boundaries around these solutions using additional constraints to narrow down the search space for better efficiency. The algorithm then explores the neighboring areas within these boundaries using a mixed integer programming (MIP) solver to find the optimal solution.

Estrada-Moreno et. al [4] tried to solve the SSCFLP with some capacity constraints. A penalty cost is considered when the maximum capacity at a facility is exceeded. In their article they purpose a biased-randomised algorithm as a solving method

Oliveira et al. [7] proposed a Dual RAMP heuristic, where the dual problem, obtained through a Lagrangean relaxation, is solved by subgradient optimisation. A local search and a Tabu Search, method are used to improve the solutions. Tabu search was also proposed by Delmaire et al. [3]

Ant Colony Optimization (ACO) was proposed by Kumweang et al. [6] to solve this problem. In their article, they show excellent results when compared to other algorithms.

Contreras et al. [2] proposed a Scatter Search approach to provide upper bounds for the optimal solution of the problem. The proposed approach uses GRASP to initialize the Reference Set. Solutions of the Reference Set are combined using a procedure that consists of two phases: the initialization phase and the improvement phase. During the initialization phase each client is assigned to an open facility to obtain a solution that is then improved with the improvement phase.

3 Problem Presentation

As previously mentioned, 440 instances were available, in 16 sets of Delmaire, Holmberg, OR, Yang and TBED1. Even in these sets, the optimal solutions were made available, in order to have a point of comparison.

In order to find the solution for each instance, each problem was solved for the three methods developed, one heuristic and two metaheuristic methods. Heuristic and metaheuristic methods to effentialy solve the problems, but it's possible to not obtain the optimal solution as the method focus more in time efficiency.

The assumption of the problem using heuristic and metaheuristic methods is based on the following objective function and all constraints and decision variables:

$$SSCFLP = min \sum_{i \varepsilon I}^{\infty} f_i y_i + \sum_{i \varepsilon I}^{\infty} \sum_{j \varepsilon J}^{\infty} c_{ij} x_{ij} \tag{1}$$

Where

$$\sum_{i \varepsilon I}^{\infty} x_{ij} = 1, \forall j \varepsilon J \tag{2}$$

$$\sum_{j \varepsilon J}^{\infty} d_j x_{ij} \leq s_i y_i, \forall i \varepsilon I \tag{3}$$

$$x_{ij} \varepsilon \{0,1\}, \forall i \varepsilon I, \forall j \varepsilon J \tag{4}$$

$$y_i \varepsilon \{0,1\}, \forall i \varepsilon I \tag{5}$$

In order to reproduce the Equations of the problem, the objective function and all constraints and decision variables, it was developed a script in Python.

3.1 Constructive heuristic

In the case of the Constructive Heuristic, it was decided to allocate customers to facilities, promoting an allocation criterion based on the lowest ratio between the cost of opening a Facility and the Facility's initial capacity.

3.2 Local Search

Two local search algorithms were implemented, the local search shift and the local search swap. In the local shift research, a neighborhood structure is applied that promotes the change of a customer's facility, if it has the capacity to support the customer's demand. However, in order to optimize this change, changes are only promoted where the cost of transport between the customer and the facility is lower than the previously assigned facility. On the other hand, in the local swap survey, based on 2 customers and the respective assigned facilities, an exchange is promoted between the facilities of the two customers, if these contain the capacity to support the customer's demand and promote a better solution, i.e., the transport cost between the client and the new facility is lower.

3.3 GRASP

The greedy randomized adaptive search procedure, GRASP, is a meta-heuristic algorithm commonly applied to enhance optimization problems. GRASP typically consists of iterations made up from successive constructions of a greedy randomized solution and subsequent iterative improvements of it through a local search.

In the current case of our problem, we started with the alpha value at 0.05 and carried out 200 iterations, with every ten iterations the alpha value increasing by the alpha value itself.

In this way, it is possible to start building the solution with as few facilities as possible, since these only appear in an RCL region. Once this region has been defined, a random Facility is chosen, to which a customer with the lowest transport cost will be assigned. In each iteration, a local search algorithm was implemented in order to improve the initial solution.

In the end, all of the solutions in each iteration were collected, and it was chosen the best solution, which is the solution with the lowest cost.

4 Computational results

Within this part, we present the outcomes of a series of evaluations performed to gauge the effectiveness of the Local Search method, in the concept of heuristic and metaheuristic, this last one was first initialized with a GRASP method, which we introduced in this manuscript to tackle the SSCFLP. Our implementation of the suggested algorithm was coded in Python and the assessments were carried out on a computer equipped with Chip Apple M2 processor, along with 16 GB of RAM and operating system Ventura 13.0. To assess the effectiveness of our algorithm in tackling the SSCFLP, we decided to utilize several datasets that are commonly known as Delmaire, Holmberg, OR-Library, Yang, and TBED1.

In the following tables, we compare, for each test problem, the solution given by Local Search method with the optimal solution of the problem from each dataset, obtained from the literature previously read.

In order to obtain results in real time, a limit of 20 minutes was defined in the solver, for each instance.

For each instance, the model and the computational results were exported, from the time the model was running, as well as the obtained solution and the difference between this and the optimal solution, the gap.

$$gap = \frac{Z - Z*}{Z*} \times 100 \tag{6}$$

4.1 Delmaire

Table 1 shows the computational results obtained for the Delmaire instances. As in these instances, the number of customers and facilities is lower, computational time is reduced and the optimal solution is obtained more quickly.

Table 1: Computacional results for Delmaire Dataset using the Exact Method

#	|I|-|J|	Z*	Z	Gap	Time
p1	10-20	2014	2014	0	661
p2	10-20	4251	4251	0	563
p3	10-20	6051	6051	0	614
p4	10-20	7168	7168	≈ 0	1624
p5	10-20	4551	4551	0	1223
p6	10-20	2269	2269	0	1935
p7	15-30	4366	4366	≈ 0	4567
p8	15-30	7926	7926	0	12981
p9	15-30	2480	2480	0	2880
p10	15-30	23112	23112	0	2674
p11	15-30	3447	3447	≈ 0	8166
p12	15-30	3711	3711	0	3923
p13	15-30	3760	3760	0	5285
p14	15-30	5965	5965	0	5831
p15	15-30	7816	7816	0	5598
p16	15-30	11543	11543	0	6643
p17	15-30	9884	9884	0	8780
p18	20-40	15607	15607	0	10875
p19	20-40	18683	18683	0	11116
p20	20-40	26561	26561	≈ 0	72196
p21	20-40	7295	7295	0	40366
p22	20-40	3271	3271	0	5419
p23	20-40	6036	6036	0	3418
p24	20-40	6327	6327	0	4441
p25	20-40	8947	8947	0	2162
p26	20-50	4448	4448	≈ 0	11238
p27	20-50	10921	10921	0	7125
p28	20-50	11117	11117	0	15268
p29	20-50	9832	9832	0	14677
p30	20-50	10816	10816	0	871670
p31	20-50	4466	4466	0	17200
p32	20-50	9881	9881	≈ 0	15855
p33	20-50	39463	39463	0	1199075
p34	30-60	4701	4701	0	19753
p35	30-60	5456	5456	0	2086
p36	30-60	16781	16781	0	36640
p37	30-60	14668	14668	0	79614
p38	30-60	47249	47249	0	20586
p39	30-60	41007	41007	0	88409
p40	30-60	61633	61636	0.005	1199401
p41	30-60	17246	17246	0	2998
p42	30-75	7887	7887	0	10463
p43	30-75	5114	5114	0	20970
p44	30-75	36022	37303	3.500	11992642
p45	30-75	17676	17676	0	4633

p46	30-75	48701	48701	0	177261
p47	30-75	66230	66230	0	659549
p48	30-75	58964	58964	0	65225
p49	30-75	79614	79659	0.06	1199777
p50	30-90	5937	5937	0	29383
p51	30-90	9060	9060	0	224940
p52	30-90	34652	34652	0	560694
p53	30-90	30038	30038	0	33280
p54	30-90	43853	43853	0	10129
p55	30-90	69610	69753	0.205	1199989
p56	30-90	64474	64478	0.006	1155
p57	30-90	49791	49791	0	611

Table 2: Computacional results for Delmaire Dataset - Heuristic constructive and Local Search Shift

#	|I|-|J|	Z*	Z Constructive	Z Local Search Shift	Gap Constructive	Gap Local Search Shift	Time Constructive	Time Local Search Shift
p1	10-20	2014	2664	2492	32.274	23.734	0.214	0.051
p2	10-20	4251	5247	5247	23.430	23.430	0.214	0.056
p3	10-20	6051	8023	7402	32.590	22.327	0.154	0.050
p4	10-20	7168	8850	8752	23.465	22.098	0.211	0.067
p5	10-20	4551	5273	5208	15.865	14.436	0.147	0.049
p6	10-20	2269	3347	2745	47.510	20.978	0.218	0.055
p7	15-30	4366	5874	4915	34.540	12.574	0.231	0.078
p8	15-30	7926	9803	9220	23.682	16.326	0.200	0.076
p9	15-30	2480	3960	3712	59.677	49.677	0.223	0.080
p10	15-30	23112	27766	27689	20.137	19.804	0.225	0.067
p11	15-30	3447	4795	4734	39.106	37.337	0.234	0.070
p12	15-30	3711	4997	4615	34.654	24.360	0.206	0.082
p13	15-30	3760	5155	4931	37.101	31.144	0.207	0.071
p14	15-30	5965	9174	7895	53.797	32.355	0.164	0.084
p15	15-30	7816	11015	9229	40.929	18.078	0.241	0.102
p16	15-30	11543	15675	13415	35.797	16.218	0.225	0.103
p17	15-30	9884	11218	11174	13.497	13.051	0.149	0.055
p18	20-40	15607	18050	18050	15.653	15.653	0.258	0.092
p19	20-40	18683	21131	20986	13.103	12.327	0.348	0.165
p20	20-40	26561	31762	31514	19.581	18.648	0.334	0.116
p21	20-40	7295	9934	9145	36.175	25.360	0.538	0.304
p22	20-40	3271	4890	4256	49.496	30.113	0.213	0.111
p23	20-40	6036	8325	7440	37.922	23.260	0.201	0.123
p24	20-40	6327	8569	7272	35.435	14.936	0.308	0.181
p25	20-40	8947	10687	10088	19.448	12.753	0.348	0.242
p26	20-50	4448	6975	6338	56.812	42.491	0.384	0.151

p27	20-50	10921	12814	12683	17.334	16.134	0.360	0.233
p28	20-50	11117	13508	13177	21.508	18.530	0.390	0.191
p29	20-50	9832	12696	11656	29.129	18.552	0.404	0.174
p30	20-50	10816	13534	13145	25.129	21.533	0.487	0.186
p31	20-50	4466	6881	5726	54.075	28.213	0.324	0.168
p32	20-50	9881	11907	11343	20.504	14.796	0.539	0.132
p33	20-50	39463	46115	45410	16.856	15.070	0.409	0.168
p34	30-60	4701	7337	6284	56.073	33.674	0.319	0.251
p35	30-60	5456	9242	7532	69.391	38.050	0.676	0.425
p36	30-60	16781	19730	19398	17.573	15.595	0.387	0.233
p37	30-60	14668	17741	16929	20.950	15.415	0.494	0.326
p38	30-60	47249	55778	52744	18.051	11.630	1.012	0.298
p39	30-60	41007	52123	50553	27.108	23.279	0.758	0.356
p40	30-60	61633	68354	68146	10.905	10.567	0.716	0.300
p41	30-60	17246	22162	21098	28.505	22.336	0.312	0.247
p42	30-75	7887	11851	9952	50.260	26.182	0.718	0.427
p43	30-75	5114	7775	7195	52.034	40.692	0.427	0.248
p44	30-75	36022	41810	40996	16.068	13.808	0.786	0.355
p45	30-75	17676	21445	20563	21.323	16.333	0.589	0.233
p46	30-75	48701	54288	53634	11.472	10.129	0.414	0.253
p47	30-75	66230	72108	71763	8.875	8.354	0.648	0.312
p48	30-75	58964	66514	65225	12.804	10.618	0.512	0.299
p49	30-75	79614	88570	87815	11.249	10.301	0.909	0.384
p50	30-90	5937	9196	8088	54.893	36.230	0.751	0.360
p51	30-90	9060	13629	11799	50.430	30.232	0.962	0.323
p52	30-90	34652	42278	40607	22.007	17.185	0.791	0.299
p53	30-90	30038	33909	33683	12.887	12.135	0.689	0.247
p54	30-90	43853	55355	53078	26.229	21.036	0.626	0.299
p55	30-90	69610	74604	74604	7.174	7.174	0.666	0.222
p56	30-90	64474	83087	80827	28.869	25.364	0.685	0.305
p57	30-90	49791	53203	52753	6.853	5.949	0.547	0.199

Table 3: Computacional results for Delmaire Dataset - Heuristic constructive and Local Search Swap

#	|I|-|J|	Z*	Z Constructive	Z Local Search Swap	Gap Constructive	Gap Local Search Swap	Time Constructive	Time Local Search Swap
p1	10-20	2014	2664	2453	32.274	21.797	0.214	0.113
p2	10-20	4251	5247	4846	23.430	13.997	0.214	0.176
p3	10-20	6051	8023	7285	32.590	20.393	0.154	0.136
p4	10-20	7168	8850	8517	23.465	18.820	0.211	0.165
p5	10-20	4551	5273	4700	15.865	3.274	0.147	0.201
p6	10-20	2269	3347	2479	47.510	9.255	0.218	0.160
p7	15-30	4366	5874	4717	34.540	8.039	0.231	0.334

p8	15-30	7926	9803	8784	23.682	10.825	0.200	0.418
p9	15-30	2480	3960	3266	59.677	31.694	0.223	0.432
p10	15-30	23112	27766	27113	20.137	17.311	0.225	0.486
p11	15-30	3447	4795	3751	39.106	8.819	0.234	0.625
p12	15-30	3711	4997	4409	34.654	18.809	0.206	0.325
p13	15-30	3760	5155	4223	37.101	12.314	0.207	0.407
p14	15-30	5965	9174	7734	53.797	29.656	0.164	0.351
p15	15-30	7816	11015	8847	40.929	13.191	0.241	0.394
p16	15-30	11543	15675	13033	35.797	12.908	0.225	0.382
p17	15-30	9884	11218	10098	13.497	2.165	0.149	0.640
p18	20-40	15607	18050	17199	15.653	10.201	0.258	1.304
p19	20-40	18683	21131	19908	13.103	6.557	0.348	1.490
p20	20-40	26561	31762	30179	19.581	13.621	0.334	1.335
p21	20-40	7295	9934	8302	36.175	13.804	0.538	1.383
p22	20-40	3271	4890	3784	49.496	15.683	0.213	0.845
p23	20-40	6036	8325	7267	37.922	20.394	0.201	0.582
p24	20-40	6327	8569	7183	35.435	13.529	0.308	0.757
p25	20-40	8947	10687	9767	19.448	9.165	0.348	1.324
p26	20-50	4448	6975	5264	56.812	18.345	0.384	1.777
p27	20-50	10921	12814	11430	17.334	4.661	0.360	2.614
p28	20-50	11117	13508	11972	21.508	7.691	0.390	3.190
p29	20-50	9832	12696	11498	29.129	16.945	0.404	0.940
p30	20-50	10816	13534	12049	25.129	11.400	0.487	1.799
p31	20-50	4466	6881	5400	54.075	20.914	0.324	1.064
p32	20-50	9881	11907	10623	20.504	7.509	0.539	1.689
p33	20-50	39463	46115	44220	16.856	12.054	0.409	2.093
p34	30-60	4701	7337	5749	56.073	22.293	0.319	1.648
p35	30-60	5456	9242	7256	69.391	32.991	0.676	2.576
p36	30-60	16781	19730	17743	17.573	5.733	0.387	17.235
p37	30-60	14668	17741	15956	20.950	8.781	0.494	4.064
p38	30-60	47249	55778	51926	18.051	9.899	1.012	3.260
p39	30-60	41007	52123	49874	27.108	21.623	0.758	3.227
p40	30-60	61633	68354	66359	10.905	7.668	0.716	6.260
p41	30-60	17246	22162	20868	28.505	21.002	0.312	1.882
p42	30-75	7887	11851	9042	50.260	14.644	0.718	5.508
p43	30-75	5114	7775	5765	52.034	12.730	0.427	8.066
p44	30-75	36022	41810	39443	16.068	9.497	0.786	5.582
p45	30-75	17676	21445	19547	21.323	10.585	0.589	4.398
p46	30-75	48701	54288	52113	11.472	7.006	0.414	5.364
p47	30-75	66230	72108	69407	8.875	4.797	0.648	10.178
p48	30-75	58964	66514	64266	12.804	8.992	0.512	4.299
p49	30-75	79614	88570	86338	11.249	8.446	0.909	5.116
p50	30-90	5937	9196	7095	54.893	19.505	0.751	5.893
p51	30-90	9060	13629	10279	50.430	13.455	0.962	12.923
p52	30-90	34652	42278	39089	22.007	12.804	0.791	10.547
p53	30-90	30038	33909	31012	12.887	3.243	0.689	12.376

p54	30-90	43853	55355	52114	26.229	18.838	0.626	6.656
p55	30-90	69610	74604	71529	7.174	2.757	0.666	13.207
p56	30-90	64474	83087	80020	28.869	24.112	0.685	6.280
p57	30-90	49791	53203	50472	6.853	1.368	0.547	13.291

Table 4: Computacional results for Delmaire Dataset - Metaheuristic Grasp and Local Search Shift

#	|I|-|J|	Z*	Z	Gap	Time Constructive	Time Local
p1	10-20	2014	2063	2.433	0.704	0.029
p2	10-20	4251	4473	5.222	0.734	0.049
p3	10-20	6051	6345	4.859	0.840	0.074
p4	10-20	7168	7968	11.161	0.818	0.054
p5	10-20	4551	5050	10.965	0.613	0.046
p6	10-20	2269	2400	5.773	0.679	0.032
p7	15-30	4366	4705	7.765	0.959	0.145
p8	15-30	7926	8879	12.024	0.580	0.056
p9	15-30	2480	2859	15.282	0.660	0.063
p10	15-30	23112	26286	13.733	0.741	0.136
p11	15-30	3447	3810	10.531	0.675	0.146
p12	15-30	3711	4064	9.512	0.660	0.117
p13	15-30	3760	4167	10.824	1.001	0.065
p14	15-30	5965	6877	15.289	1.064	0.072
p15	15-30	7816	8857	13.319	0.868	0.085
p16	15-30	11543	12338	6.887	0.948	0.072
p17	15-30	9884	11222	13.537	0.741	0.109
p18	20-40	15607	17570	12.578	0.784	0.086
p19	20-40	18683	22267	19.183	0.740	0.256
p20	20-40	26561	30010	12.985	0.641	0.189
p21	20-40	7295	8077	10.720	0.820	0.106
p22	20-40	3271	3695	12.962	0.685	0.112
p23	20-40	6036	6941	14.993	0.763	0.086
p24	20-40	6327	7076	11.838	1.288	0.165
p25	20-40	8947	10254	14.608	0.865	0.121
p26	20-50	4448	5089	14.411	1.157	0.125
p27	20-50	10921	12582	15.209	1.060	0.229
p28	20-50	11117	11827	6.387	1.422	0.103
p29	20-50	9832	11556	17.535	1.266	0.206
p30	20-50	10816	11763	8.756	0.835	0.131
p31	20-50	4466	5301	18.697	0.880	0.125
p32	20-50	9881	10359	4.838	0.835	0.195
p33	20-50	39463	44581	12.969	0.981	0.133
p34	30-60	4701	5350	13.806	1.288	0.304
p35	30-60	5456	6736	23.460	1.097	0.137

p36	30-60	16781	19984	19.087	1.665	0.196
p37	30-60	14668	16155	10.138	1.778	0.184
p38	30-60	47249	60052	27.097	1.665	0.183
p39	30-60	41007	50271	22.591	1.090	0.167
p40	30-60	61633	72358	17.401	1.151	0.223
p41	30-60	17246	17501	1.479	1.103	0.128
p42	30-75	7887	10016	26.994	1.534	0.235
p43	30-75	5114	5908	15.526	1.751	0.274
p44	30-75	36022	44869	24.560	1.337	0.270
p45	30-75	17676	21739	22.986	1.719	0.356
p46	30-75	48701	63489	30.365	1.528	0.862
p47	30-75	66230	88278	33.290	1.302	0.546
p48	30-75	58964	64606	9.569	1.777	0.295
p49	30-75	79614	94889	19.186	1.298	0.229
p50	30-90	5937	6281	5.794	1.350	0.223
p51	30-90	9060	11010	21.523	1.420	0.299
p52	30-90	34652	36868	6.395	1.292	0.190
p53	30-90	30038	33720	12.258	1.481	0.267
p54	30-90	43853	47860	9.137	1.730	0.218
p55	30-90	69610	85635	23.021	2.084	0.482
p56	30-90	64474	86627	34.360	1.389	0.257
p57	30-90	49791	50487	1.398	1.748	0.320

Table 5: Computacional results for Delmaire Dataset - Metaheuristic Grasp and Local Search Swap

#	**|I|-|J|**	**Z***	**Z**	**Gap**	**Time Constructive**	**Time Local**
p1	10-20	2014	2006	0.397	0.853	0.204
p2	10-20	4251	4449	4.658	0.712	0.218
p3	10-20	6051	6120	1.140	0.945	0.238
p4	10-20	7168	7973	11.230	1.482	0.247
p5	10-20	4551	4981	9.448	2.187	0.913
p6	10-20	2269	2345	3.349	1.002	0.219
p7	15-30	4366	4856	11.223	1.218	0.358
p8	15-30	7926	8936	12.743	1.065	0.315
p9	15-30	2480	2736	10.323	1.061	0.373
p10	15-30	23112	26004	12.513	1.124	0.402
p11	15-30	3447	3800	10.241	0.932	0.523
p12	15-30	3711	4047	9.054	1.154	0.346
p13	15-30	3760	4090	8.777	1.560	0.422
p14	15-30	5965	6192	3.806	0.942	0.377
p15	15-30	7816	8456	8.188	0.950	0.412
p16	15-30	11543	13059	13.134	0.946	0.380
p17	15-30	9884	10068	1.862	0.966	0.668

p18	20-40	15607	17363	11.251	1.184	0.575
p19	20-40	18683	20858	11.642	1.190	0.929
p20	20-40	26561	29376	10.598	1.062	0.561
p21	20-40	7295	8242	12.981	1.907	0.891
p22	20-40	3271	3606	10.242	1.506	0.596
p23	20-40	6036	6769	12.144	1.790	0.907
p24	20-40	6327	7477	18.176	1.462	0.797
p25	20-40	8947	10035	12.161	7.960	0.642
p26	20-50	4448	4967	11.668	1.207	1.029
p27	20-50	10921	12801	17.215	1.123	1.081
p28	20-50	11117	11766	5.838	1.275	1.201
p29	20-50	9832	11228	14.199	1.100	0.962
p30	20-50	10816	11818	9.264	1.250	1.267
p31	20-50	4466	5177	15.920	1.523	1.168
p32	20-50	9881	10875	10.060	1.526	1.117
p33	20-50	39463	44627	13.086	1.524	2.201
p34	30-60	4701	5514	17.294	1.646	1.386
p35	30-60	5456	6351	16.404	1.591	1.987
p36	30-60	16781	19903	18.604	4.235	2.775
p37	30-60	14668	15677	6.879	1.481	1.949
p38	30-60	47249	64661	36.852	1.329	1.372
p39	30-60	41007	50703	23.645	1.820	1.626
p40	30-60	61633	69416	12.628	1.947	1.814
p41	30-60	17246	18140	5.184	1.478	2.026
p42	30-75	7887	9782	24.027	2.088	3.630
p43	30-75	5114	5447	6.512	2.042	2.808
p44	30-75	36022	43819	21.645	1.503	1.928
p45	30-75	17676	21769	23.156	2.134	2.630
p46	30-75	48701	59464	22.100	1.885	3.131
p47	30-75	66230	87630	32.312	1.598	2.627
p48	30-75	58964	64560	9.491	1.625	3.193
p49	30-75	79614	101768	27.827	2.757	2.796
p50	30-90	5937	6467	8.927	2.078	4.208
p51	30-90	9060	10952	20.883	1.660	3.659
p52	30-90	34652	36782	6.147	1.572	2.745
p53	30-90	30038	36118	20.241	2.032	4.632
p54	30-90	43853	47840	9.092	1.684	2.334
p55	30-90	69610	90464	29.958	1.998	5.797
p56	30-90	64474	86548	34.237	2.115	3.836
p57	30-90	49791	54730	9.919	1.791	4.919

4.2 Holmberg

Table 2 represents Holmberg's computational results, the one in which the computational time is faster, obtaining optimal solutions in a shorter time. However, in the last instances it is possible to verify that the complexity increases, as it has more clients and facilities.

Table 6: Computacional results for Holmberg Dataset using the Exact Method

#	|I|-|J|	Z*	Z	Gap	Time
p1	10-50	8848	8848	0	105
p2	10-50	7913	7913	0	67
p3	10-50	9314	9314	0	94
p4	10-50	10714	10714	0	354
p5	10-50	8838	8838	≈ 0	74
p6	10-50	7777	7777	≈ 0	59
p7	10-50	9488	9488	≈ 0	141
p8	10-50	11088	11088	0	423
p9	10-50	8462	8462	0	76
p10	10-50	7617	7617	≈ 0	61
p11	10-50	8932	8932	0	85
p12	10-50	10132	10132	0	131
p13	20-50	8252	8252	≈ 0	201
p14	20-50	7137	7137	0	101
p15	20-50	8808	8808	0	171
p16	20-50	10408	10408	≈ 0	270
p17	20-50	8227	8227	0	169
p18	20-50	7125	7125	≈ 0	94
p19	20-50	8886	8886	≈ 0	488
p20	20-50	10486	10486	≈ 0	782
p21	20-50	8068	8068	0	115
p22	20-50	7092	7092	0	96
p23	20-50	8746	8746	0	226
p24	20-50	10273	10273	0	433
p25	30-150	11630	11630	0	4596
p26	30-150	10771	10771	0	1769
p27	30-150	12322	12322	0	13082
p28	30-150	13722	13722	0	8487
p29	30-150	12371	12371	0	16619
p30	30-150	11331	11331	≈ 0	33944
p31	30-150	13331	13331	0	52446
p32	30-150	15331	15331	0	39277
p33	30-150	11629	11629	0	2727
p34	30-150	10632	10632	0	1447
p35	30-150	12232	12232	0	2205
p36	30-150	13832	13832	0	5706
p37	30-150	11258	11258	0	1070
p38	30-150	10551	10551	0	893
p39	30-150	11824	11824	0	1111
p40	30-150	13024	13024	0	1488
p41	10-90	6589	6589	0	1516
p42	20-80	5663	5663	0	2878

p43	30-70	5214	5214	0	463
p44	10-90	7028	7028	0	356
p45	20-80	6251	6251	0	426
p46	30-70	5651	5651	≈ 0	815
p47	10-90	6228	6228	0	86
p48	20-80	5596	5596	0	233
p49	30-70	5302	5302	≈ 0	446
p50	10-100	8741	8741	0	3476
p51	20-100	7414	7414	0	4189
p52	10-100	9178	9178	≈ 0	366
p53	20-100	8531	8531	0	245
p54	10-100	8777	8777	0	150
p55	20-100	7654	7654	≈ 0	816
p56	30-200	21103	21103	0	12071
p57	30-200	26039	26039	0	72795
p58	30-200	37239	37239	0	673029
p59	30-200	27282	27282	0	22506
p60	30-200	20534	20534	≈ 0	1341
p61	30-200	24454	24454	1385	≈ 0
p62	30-200	32643	32643	0	25449
p63	30-200	25105	25105	0	1932
p64	30-200	20530	20530	0	1458
p65	30-200	24445	24445	0	1679
p66	30-200	31415	31415	0	30557
p67	30-200	24848	24848	0	4923
p68	30-200	20538	20538	0	1058
p69	30-200	24532	24532	0	1460
p70	30-200	32321	32321	0	16312
p71	30-200	25540	25540	0	3642

Table 7: Computacional results for Holmberg Dataset - Heuristic constructive and Local Search Shift

#	|I|-|J|	Z*	Z Constructive	Z Local Search Shift	Gap Constructive	Gap Local Search Shift	Time Constructive	Time Local Search Shift
p1	10-50	8848	22293	19635	151.955	121.915	0.343	0.171
p2	10-50	7913	22142	19140	179.818	141.880	0.191	0.093
p3	10-50	9314	23142	20140	148.465	116.234	0.249	0.148
p4	10-50	10714	24142	21140	125.331	97.312	0.295	0.101
p5	10-50	8838	21441	16626	142.600	88.119	0.334	0.110
p6	10-50	7777	23827	18831	206.378	142.137	0.246	0.112
p7	10-50	9488	25427	20431	167.991	115.335	0.240	0.112
p8	10-50	11088	27027	22031	143.750	98.692	0.356	0.148
p9	10-50	8462	22330	21097	163.886	149.315	0.185	0.070

p10	10-50	7617	20878	18966	174.097	148.996	0.178	0.072
p11	10-50	8932	21878	19966	144.940	123.533	0.171	0.079
p12	10-50	10132	22878	20966	125.799	106.929	0.383	0.073
p13	20-50	8252	23778	21617	188.148	161.961	0.258	0.125
p14	20-50	7137	22952	18246	221.592	155.654	0.226	0.131
p15	20-50	8808	24352	19646	176.476	123.047	0.284	0.146
p16	20-50	10408	25752	21046	147.425	102.210	0.361	0.200
p17	20-50	8227	22319	17426	171.290	111.815	0.286	0.138
p18	20-50	7125	22691	16763	218.470	135.270	0.472	0.265
p19	20-50	8886	24291	18363	173.363	106.651	0.456	0.164
p20	20-50	10486	25891	19963	146.910	90.378	0.377	0.156
p21	20-50	8068	21453	19326	165.902	139.539	0.281	0.111
p22	20-50	7092	22937	20216	223.421	185.054	0.243	0.105
p23	20-50	8746	24137	21416	175.978	144.866	0.229	0.103
p24	20-50	10273	25337	22616	146.637	120.150	0.227	0.106
p25	30-150	11630	84992	72256	630.800	521.290	0.617	0.377
p26	30-150	10771	76696	55975	612.060	419.682	0.773	0.412
p27	30-150	12322	77896	57175	532.170	364.007	1.124	0.632
p28	30-150	13722	79096	58375	476.417	325.412	0.936	0.518
p29	30-150	12371	85269	74764	589.265	504.349	1.341	0.566
p30	30-150	11331	84662	80223	647.171	607.996	1.574	0.655
p31	30-150	13331	86862	82423	551.579	518.281	1.343	0.583
p32	30-150	15331	89062	84623	480.928	451.973	1.121	0.533
p33	30-150	11629	97680	85561	739.969	635.755	1.526	0.459
p34	30-150	10632	77521	63737	629.129	499.483	1.066	0.673
p35	30-150	12232	79121	65337	546.836	434.148	1.063	0.583
p36	30-150	13832	80721	66937	483.582	383.929	0.935	0.377
p37	30-150	11258	120173	120173	967.445	967.445	0.768	0.444
p38	30-150	10551	74658	74658	607.592	607.592	0.751	0.282
p39	30-150	11824	75658	75658	539.868	539.868	0.603	0.364
p40	30-150	13024	76658	76658	488.590	488.590	1.118	0.332
p41	10-90	6589	12911	9574	95.948	45.303	0.484	0.256
p42	20-80	5663	11956	8759	111.125	54.671	0.471	0.303
p43	30-70	5214	10728	7951	105.754	52.493	0.414	0.337
p44	10-90	7028	18677	17805	165.751	153.344	0.419	0.170
p45	20-80	6251	16789	10744	168.581	71.876	0.446	0.307
p46	30-70	5651	15899	13976	181.348	147.319	0.462	0.253
p47	10-90	6228	19676	17200	215.928	176.172	0.458	0.170
p48	20-80	5596	15200	10527	171.623	88.117	0.410	0.269
p49	30-70	5302	7453	7329	40.570	38.231	0.563	0.343
p50	10-100	8741	18446	14672	111.028	67.853	0.530	0.317
p51	20-100	7414	18851	14821	154.262	99.906	0.535	0.429
p52	10-100	9178	22272	19414	142.667	111.528	0.626	0.260
p53	20-100	8531	20533	18945	140.687	122.072	0.429	0.265
p54	10-100	8777	26869	26175	206.130	198.223	0.525	0.238
p55	20-100	7654	22240	19084	190.567	149.334	0.386	0.216

p56	30-200	21103	82211	60254	289.570	185.523	2.273	0.729
p57	30-200	26039	87011	65054	234.156	149.833	1.845	0.647
p58	30-200	37239	98211	76254	163.732	104.769	1.934	0.816
p59	30-200	27282	80929	58456	196.639	114.266	2.672	0.709
p60	30-200	20534	81784	62055	298.286	202.206	2.332	1.029
p61	30-200	24454	85084	65355	247.935	167.257	2.118	0.597
p62	30-200	32643	92784	73055	184.239	123.800	1.850	0.825
p63	30-200	25105	75533	53976	200.868	115.001	1.718	0.892
p64	30-200	20530	81465	68364	296.810	232.996	1.576	0.726
p65	30-200	24445	83865	70764	243.076	189.483	1.592	0.522
p66	30-200	31415	89465	76364	184.784	143.081	1.382	0.719
p67	30-200	24848	83136	65289	234.578	162.754	1.561	0.633
p68	30-200	20538	88659	54342	331.683	164.592	1.701	0.614
p69	30-200	24532	91359	57042	272.407	132.521	1.782	0.617
p70	30-200	32321	97659	63342	202.153	95.978	1.360	0.623
p71	30-200	25540	76795	64252	200.685	151.574	2.436	1.045

Table 8: Computacional results for Delmaire Dataset - Heuristic constructive and Local Search Swap

#	|I|-|J|	Z*	Z Constructive	Z Local Search Swap	Gap Constructive	Gap Local Search Swap	Time Constructive	Time Local Search Swap
p1	10-50	8848	22293	16514	151.955	86.641	0.343	1.424
p2	10-50	7913	22142	16544	179.818	109.074	0.191	1.285
p3	10-50	9314	23142	17544	148.465	88.362	0.249	1.722
p4	10-50	10714	24142	18544	125.331	73.082	0.295	1.184
p5	10-50	8838	21441	13324	142.600	50.758	0.334	1.452
p6	10-50	7777	23827	13005	206.378	67.224	0.246	1.452
p7	10-50	9488	25427	14605	167.991	53.931	0.240	1.442
p8	10-50	11088	27027	16205	143.750	46.149	0.356	2.009
p9	10-50	8462	22330	13991	163.886	65.339	0.185	1.577
p10	10-50	7617	20878	10386	174.097	36.353	0.178	1.868
p11	10-50	8932	21878	11386	144.940	27.474	0.171	1.819
p12	10-50	10132	22878	12386	125.799	22.246	0.383	1.920
p13	20-50	8252	23778	14386	188.148	74.333	0.258	1.788
p14	20-50	7137	22952	14328	221.592	100.757	0.226	1.290
p15	20-50	8808	24352	15728	176.476	78.565	0.284	1.340
p16	20-50	10408	25752	17128	147.425	64.566	0.361	1.571
p17	20-50	8227	22319	12182	171.290	48.073	0.286	1.705
p18	20-50	7125	22691	12545	218.470	76.070	0.472	1.608
p19	20-50	8886	24291	14145	173.363	59.183	0.456	1.487
p20	20-50	10486	25891	15745	146.910	50.153	0.377	1.680
p21	20-50	8068	21453	15034	165.902	86.341	0.281	1.702
p22	20-50	7092	22937	14585	223.421	105.654	0.243	1.828

p23	20-50	8746	24137	15785	175.978	80.483	0.229	1.397
p24	20-50	10273	25337	16985	146.637	65.336	0.227	1.608
p25	30-150	11630	84992	51925	630.800	346.475	0.617	27.180
p26	30-150	10771	76696	41259	612.060	283.056	0.773	28.593
p27	30-150	12322	77896	42459	532.170	244.579	1.124	25.680
p28	30-150	13722	79096	43659	476.417	218.168	0.936	27.250
p29	30-150	12371	85269	56865	589.265	359.664	1.341	23.962
p30	30-150	11331	84662	49772	647.171	339.255	1.574	59.691
p31	30-150	13331	86862	51972	551.579	289.858	1.343	48.730
p32	30-150	15331	89062	54172	480.928	253.349	1.121	48.566
p33	30-150	11629	97680	67018	739.969	476.301	1.526	31.502
p34	30-150	10632	77521	52423	629.129	393.068	1.066	31.765
p35	30-150	12232	79121	54023	546.836	341.653	1.063	27.764
p36	30-150	13832	80721	55623	483.582	302.133	0.935	27.047
p37	30-150	11258	120173	97840	967.445	769.071	0.768	30.938
p38	30-150	10551	74658	65411	607.592	519.951	0.751	21.838
p39	30-150	11824	75658	66411	539.868	461.663	0.603	22.269
p40	30-150	13024	76658	67411	488.590	417.591	1.118	24.753
p41	10-90	6589	12911	9293	95.948	41.038	0.484	4.092
p42	20-80	5663	11956	8759	111.125	54.671	0.471	2.093
p43	30-70	5214	10728	7951	105.754	52.493	0.414	1.409
p44	10-90	7028	18677	12234	165.751	74.075	0.419	11.309
p45	20-80	6251	16789	9239	168.581	47.800	0.446	5.491
p46	30-70	5651	15899	13338	181.348	136.029	0.462	2.243
p47	10-90	6228	19676	10707	215.928	71.917	0.458	14.206
p48	20-80	5596	15200	10351	171.623	84.971	0.410	3.259
p49	30-70	5302	7453	7329	40.570	38.231	0.563	1.712
p50	10-100	8741	18446	12740	111.028	45.750	0.530	10.348
p51	20-100	7414	18851	14504	154.262	95.630	0.535	3.820
p52	10-100	9178	22272	17314	142.667	88.647	0.626	8.772
p53	20-100	8531	20533	16296	140.687	91.021	0.429	13.091
p54	10-100	8777	26869	15736	206.130	79.287	0.525	18.656
p55	20-100	7654	22240	18356	190.567	139.822	0.386	5.094
p56	30-200	21103	82211	38146	289.570	80.761	2.273	97.974
p57	30-200	26039	87011	42946	234.156	64.930	1.845	92.145
p58	30-200	37239	98211	54146	163.732	45.401	1.934	97.768
p59	30-200	27282	80929	37514	196.639	37.505	2.672	148.607
p60	30-200	20534	81784	43595	298.286	112.306	2.332	97.809
p61	30-200	24454	85084	46895	247.935	91.768	2.118	106.172
p62	30-200	32643	92784	54595	184.239	67.249	1.850	97.255
p63	30-200	25105	75533	39101	200.868	55.750	1.718	100.694
p64	30-200	20530	81465	44368	296.810	116.113	1.576	95.848
p65	30-200	24445	83865	46768	243.076	91.319	1.592	91.960
p66	30-200	31415	89465	52368	184.784	66.697	1.382	117.281
p67	30-200	24848	83136	42682	234.578	71.772	1.561	84.289
p68	30-200	20538	88659	36948	331.683	79.901	1.701	75.382

p69	30-200	24532	91359	39648	272.407	61.617	1.782	94.432
p70	30-200	32321	97659	45948	202.153	42.161	1.360	82.411
p71	30-200	25540	76795	34708	200.685	35.897	2.436	164.174

Table 9: Computacional results for Holmberg Dataset - Metaheuristic Grasp and Local Search Shift

#	|I|-|J|	Z*	Z	Gap	Time Constructive	Time Local
p1	10-50	8848	9274	4.815	0.770	0.078
p2	10-50	7913	8655	9.377	0.884	0.191
p3	10-50	9314	10120	8.654	0.825	0.204
p4	10-50	10714	11779	9.940	0.874	0.175
p5	10-50	8838	9300	5.227	0.724	0.078
p6	10-50	7777	8424	8.319	0.853	0.076
p7	10-50	9488	9967	5.048	0.770	0.094
p8	10-50	11088	11350	2.363	0.752	0.073
p9	10-50	8462	10634	25.668	1.009	0.069
p10	10-50	7617	8751	14.888	1.040	0.125
p11	10-50	8932	9857	10.356	0.744	0.058
p12	10-50	10132	11393	12.446	0.724	0.119
p13	20-50	8252	9672	17.208	0.912	0.126
p14	20-50	7137	8668	21.452	0.842	0.098
p15	20-50	8808	10805	22.673	1.009	0.214
p16	20-50	10408	11847	13.826	1.026	0.099
p17	20-50	8227	9447	14.829	1.008	0.100
p18	20-50	7125	8278	16.182	0.828	0.091
p19	20-50	8886	10378	16.790	0.876	0.098
p20	20-50	10486	11667	11.263	0.937	0.210
p21	20-50	8068	9583	18.778	0.903	0.076
p22	20-50	7092	9333	31.599	0.772	0.082
p23	20-50	8746	10421	19.152	0.866	0.078
p24	20-50	10273	12410	20.802	0.911	0.191
p25	30-150	11630	20348	74.961	2.149	0.249
p26	30-150	10771	17570	63.123	1.923	0.503
p27	30-150	12322	23536	91.008	2.566	0.361
p28	30-150	13722	22459	63.671	1.880	0.381
p29	30-150	12371	26400	113.402	1.734	0.392
p30	30-150	11331	22573	99.215	2.002	0.558
p31	30-150	13331	26773	100.833	1.807	0.273
p32	30-150	15331	26253	71.241	1.832	0.396
p33	30-150	11629	21901	88.331	2.567	0.534
p34	30-150	10632	21780	104.853	2.073	0.354
p35	30-150	12232	26593	117.405	1.919	0.747
p36	30-150	13832	24871	79.808	1.718	0.519

p37	30-150	11258	28356	151.874	2.181	0.227
p38	30-150	10551	21305	101.924	1.886	0.217
p39	30-150	11824	25194	113.075	1.678	0.221
p40	30-150	13024	24287	86.479	1.749	0.533
p41	10-90	6589	6992	6.116	0.836	0.146
p42	20-80	5663	6056	6.940	1.038	0.165
p43	30-70	5214	5670	8.746	1.477	0.171
p44	10-90	7028	7888	12.237	1.176	0.178
p45	20-80	6251	7120	13.902	1.085	0.201
p46	30-70	5651	6678	18.174	1.324	0.179
p47	10-90	6228	7300	17.213	0.997	0.127
p48	20-80	5596	6793	21.390	0.942	0.277
p49	30-70	5302	6239	17.673	1.147	0.169
p50	10-100	8741	9456	8.180	1.090	0.150
p51	20-100	7414	9040	21.931	1.138	0.162
p52	10-100	9178	11162	21.617	1.054	0.162
p53	20-100	8531	11271	32.118	1.589	0.192
p54	10-100	8777	10309	17.455	0.918	0.179
p55	20-100	7654	9250	20.852	1.066	0.426
p56	30-200	21103	25240	19.604	2.340	1.158
p57	30-200	26039	29529	13.403	2.047	1.175
p58	30-200	37239	42107	13.072	2.246	0.702
p59	30-200	27282	33013	21.007	2.371	1.120
p60	30-200	20534	25217	22.806	3.195	0.761
p61	30-200	24454	28563	16.803	2.229	0.592
p62	30-200	32643	37729	15.581	2.661	1.008
p63	30-200	25105	30034	19.634	2.892	0.472
p64	30-200	20530	28790	40.234	2.734	0.683
p65	30-200	24445	29291	19.824	2.163	0.905
p66	30-200	31415	36005	14.611	2.101	0.940
p67	30-200	24848	29363	18.170	2.524	0.479
p68	30-200	20538	26613	29.579	2.646	1.085
p69	30-200	24532	30396	23.903	3.760	0.933
p70	30-200	32321	37238	15.213	2.000	0.799
p71	30-200	25540	30129	17.968	2.334	0.460

Table 10: Computacional results for Holmberg Dataset - Metaheuristic Grasp and Local Search Swap

#	**|I|-|J|**	**Z***	**Z**	**Gap**	**Time Constructive**	**Time Local**
p1	10-50	8848	9943	12.376	2.764	1.242
p2	10-50	7913	9117	15.215	1.150	1.718
p3	10-50	9314	10407	11.735	1.163	0.621
p4	10-50	10714	11444	6.814	0.877	1.080

p5	10-50	8838	9586	8.463	1.074	0.648
p6	10-50	7777	8729	12.241	1.063	0.626
p7	10-50	9488	10319	8.758	1.024	1.069
p8	10-50	11088	12109	9.208	0.957	1.324
p9	10-50	8462	9955	17.644	0.887	0.832
p10	10-50	7617	9180	20.520	1.074	0.994
p11	10-50	8932	10285	15.148	1.045	2.612
p12	10-50	10132	10729	5.892	1.132	1.448
p13	20-50	8252	9739	18.020	1.088	0.760
p14	20-50	7137	9032	26.552	1.264	0.959
p15	20-50	8808	10248	16.349	1.177	1.134
p16	20-50	10408	11893	14.268	1.423	1.245
p17	20-50	8227	9434	14.671	1.016	1.461
p18	20-50	7125	8956	25.698	1.389	1.390
p19	20-50	8886	10799	21.528	1.302	1.125
p20	20-50	10486	12349	17.767	1.297	0.896
p21	20-50	8068	10103	25.223	1.381	1.041
p22	20-50	7092	9183	29.484	1.417	1.296
p23	20-50	8746	10143	15.973	2.038	1.337
p24	20-50	10273	11391	10.883	1.251	0.836
p25	30-150	11630	24570	111.264	2.749	32.361
p26	30-150	10771	19642	82.360	3.335	25.361
p27	30-150	12322	23354	89.531	2.386	26.627
p28	30-150	13722	21953	59.984	2.498	31.794
p29	30-150	12371	25030	102.328	2.388	18.612
p30	30-150	11331	21668	91.228	3.323	25.227
p31	30-150	13331	21937	64.556	2.327	27.954
p32	30-150	15331	29643	93.353	3.758	18.495
p33	30-150	11629	23529	102.330	2.354	29.801
p34	30-150	10632	23994	125.677	2.221	24.230
p35	30-150	12232	24492	100.229	2.475	17.380
p36	30-150	13832	25591	85.013	3.408	15.298
p37	30-150	11258	22177	96.989	2.772	17.251
p38	30-150	10551	18588	76.173	2.380	12.701
p39	30-150	11824	22040	86.401	2.961	13.169
p40	30-150	13024	18285	40.395	2.532	17.078
p41	10-90	6589	6892	4.599	1.550	6.966
p42	20-80	5663	6500	14.780	1.617	2.984
p43	30-70	5214	6227	19.428	1.472	2.674
p44	10-90	7028	8380	19.237	1.592	5.240
p45	20-80	6251	7701	23.196	1.405	1.680
p46	30-70	5651	6782	20.014	1.754	2.221
p47	10-90	6228	7785	25.000	1.119	3.714
p48	20-80	5596	6941	24.035	1.310	3.873
p49	30-70	5302	6600	24.481	1.394	2.964
p50	10-100	8741	9789	11.989	1.373	8.145

p51	20-100	7414	9233	24.535	1.867	8.492
p52	10-100	9178	10746	17.084	1.113	13.072
p53	20-100	8531	11991	40.558	1.986	7.439
p54	10-100	8777	10444	18.993	1.204	8.240
p55	20-100	7654	10085	31.761	2.097	7.038
p56	30-200	21103	26028	23.338	2.635	31.746
p57	30-200	26039	30991	19.018	2.558	29.238
p58	30-200	37239	41896	12.506	3.763	24.116
p59	30-200	27282	31764	16.428	3.984	55.997
p60	30-200	20534	27946	36.096	3.392	31.298
p61	30-200	24454	29755	21.677	4.001	32.506
p62	30-200	32643	38763	18.748	2.794	28.526
p63	30-200	25105	28787	14.666	2.836	30.367
p64	30-200	20530	29253	42.489	2.830	26.816
p65	30-200	24445	30394	24.336	2.835	36.622
p66	30-200	31415	35655	13.497	2.743	26.340
p67	30-200	24848	31512	26.819	2.812	23.042
p68	30-200	20538	26465	28.859	2.858	29.375
p69	30-200	24532	32125	30.951	2.918	30.434
p70	30-200	32321	36993	14.455	4.097	33.279
p71	30-200	25540	28749	12.565	3.848	32.075

4.3 OR-Library

Table 3 represents the Or-Library computational results. It appears that over the instances, the number of customers and facilities increases, which increases the complexity of the problem that Solver has to solve. In this sense, the computational time and the gap increase, since the solver failed to obtain the optimal solution.

Table 11: Computacional results for OR-Library Dataset using the Exact Method

#	**|I|-|J|**	**Z***	**Z**	**Gap**	**Time**
p1	16-50	932615.75	932615.75	0	92
p2	16-50	977799.4	977799.4	0	101
p3	16-50	1014099.61	1014099.613	≈ 0	150
p4	16-50	1053197.44	1053197.438	≈ 0	381
p5	16-50	932615.75	932615.75	0	35
p6	16-50	977799.4	977799.4	0	33
p7	16-50	1010641.45	1010641.45	≈ 0	36
p8	16-50	1034976.97	1034976.975	≈ 0	40
p9	25-50	796648.44	796648.4375	≈ 0	138
p10	25-50	858109.32	858158.825	0.006	172
p11	25-50	900760.11	900760.1125	≈ 0	469
p12	25-50	950608.42	950608.425	≈ 0	1239
p13	25-50	796648.44	796648.4375	≈ 0	47

p14	25-50	854704.2	854704.2	≈ 0	45
p15	25-50	893782.11	893782.1125	≈ 0	60
p16	25-50	928941.75	928941.75	0	48
p17	50-50	793439.56	793439.5625	≈ 0	294
p18	50-50	854900.45	854900.45	≈ 0	418
p19	50-50	898266.08	898266.075	≈ 0	597
p20	50-50	950608.43	950608.425	≈ 0	1077
p21	50-50	793439.56	793439.5625	≈ 0	90
p22	50-50	851495.32	851495.325	≈ 0	76
p23	50-50	893076.71	893076.7125	≈ 0	80
p24	50-50	928941.75	928941.75	0	82
p25	100-1000	19241056.93	24087455.7	25.188	1201474
p26	100-1000	18438329.78	22387298.58	21.417	1358354
p27	100-1000	17765201.95	21691404.4	22.101	1200884
p28	100-1000	17160612.23	23480262.55	36.827	1202506
p29	100-1000	13657464.23	17177245.06	25.772	1202619
p30	100-1000	13362529.34	24812870.71	85.690	5305735
p31	100-1000	13199213.19	16148228.73	22.342	1202717
p32	100-1000	13083203.74	17440075.6	33.301	1203377
p33	100-1000	11647410.5	15970915.31	37.120	1201905
p34	100-1000	11570437.68	15448792.34	33.520	1205123
p35	100-1000	11519169.78	14986880.33	30.104	1206215
p36	100-1000	11505861.86	13807396.6	20.003	1203678

Table 12: Computacional results for OR-Library Dataset - Heuristic constructive and Local Search Shift

#	|I|-|J|	Z*	Z Constructive	Z Local Search Shift	Gap Constructive	Gap Local Search Shift	Time Constructive	Time Local Search Shift
p1	16-50	932615.750	1546761.575	1502003.813	65.852	61.053	0.339	0.147
p2	16-50	977799.400	1561761.575	1517003.813	59.722	55.145	0.395	0.202
p3	16-50	1014099.610	1576761.575	1532003.813	55.484	51.070	0.242	0.136
p4	16-50	1053197.440	1599261.575	1554503.813	51.848	47.599	2.745	0.145
p5	16-50	932615.750	1248142.900	1248142.900	33.832	33.832	0.303	0.232
p6	16-50	977799.400	1248142.900	1248142.900	27.648	27.648	0.164	0.071
p7	16-50	1010641.450	1248142.900	1248142.900	23.500	23.500	0.151	0.077
p8	16-50	1034976.970	1248142.900	1248142.900	20.596	20.596	0.379	0.102
p9	25-50	796648.440	1546761.575	1502003.813	94.159	88.540	0.262	0.148
p10	25-50	858109.320	1561761.575	1517003.813	82.000	76.784	0.502	0.177
p11	25-50	900760.110	1576761.575	1532003.813	75.048	70.079	1.670	0.160
p12	25-50	950608.420	1599261.575	1554503.813	68.236	63.527	0.271	0.209
p13	25-50	796648.440	1248142.900	1248142.900	56.674	56.674	0.190	0.098
p14	25-50	854704.200	1248142.900	1248142.900	46.032	46.032	0.659	0.107

p15	25-50	893782.110	1248142.900	1248142.900	39.647	39.647	0.737	0.109
p16	25-50	928941.750	1248142.900	1248142.900	34.362	34.362	0.192	0.100
p17	50-50	793439.560	2283329.775	2230895.575	187.776	181.168	0.309	0.257
p18	50-50	854900.450	2298329.775	2245895.575	168.842	162.708	0.347	0.171
p19	50-50	898266.080	2313329.775	2260895.575	157.533	151.696	0.481	0.296
p20	50-50	950608.430	2335829.775	2283395.575	145.719	140.204	0.321	0.283
p21	50-50	793439.560	1248142.900	1248142.900	57.308	57.308	0.220	0.127
p22	50-50	851495.320	1248142.900	1248142.900	46.582	46.582	0.241	0.183
p23	50-50	893076.710	1248142.900	1248142.900	39.758	39.758	0.221	0.193
p24	50-50	928941.750	1248142.900	1248142.900	34.362	34.362	0.226	0.191
p25	100-1000	19241056.930	41805566.140	33147439.680	117.273	72.275	19.802	8.870
p26	100-1000	18438329.780	40569173.490	30937065.960	120.026	67.787	15.413	5.919
p27	100-1000	17765201.950	38792572.920	31462045.990	118.363	77.099	18.321	5.642
p28	100-1000	17160612.230	37495061.230	33157091.760	118.495	93.216	11.988	5.219
p29	100-1000	13657464.230	37796619.930	26589879.690	176.747	94.691	27.998	10.622
p30	100-1000	13362529.340	35237912.710	27376462.740	163.707	104.875	21.712	7.525
p31	100-1000	13199213.190	33682207.220	23822190.160	155.183	80.482	29.851	10.081
p32	100-1000	13083203.740	32396758.770	24310722.910	147.621	85.816	17.603	7.665
p33	100-1000	11647410.500	34695475.230	24990910.990	197.881	114.562	38.465	11.022
p34	100-1000	11570437.680	33233824.430	30680664.920	187.230	165.164	20.502	9.087
p35	100-1000	11519169.780	31616521.650	29025849.720	174.469	151.979	25.759	7.597
p36	100-1000	11505861.860	32092539.080	21782737.300	178.923	89.319	23.531	10.844

Table 13: Computacional results for OR-Library Dataset - Heuristic constructive and Local Search Swap

#	|I|-|J|	Z*	Z Constructive	Z Local Search Swap	Gap Constructive	Gap Local Search Swap	Time Constructive	Time Local Search Swap
p1	16-50	932615.750	1546761.575	1347029.813	65.852	44.436	0.339	2.120
p2	16-50	977799.400	1561761.575	1362029.813	59.722	39.295	0.395	2.178
p3	16-50	1014099.610	1576761.575	1377029.813	55.484	35.788	0.242	2.044
p4	16-50	1053197.440	1599261.575	1399529.813	51.848	32.884	2.745	1.852
p5	16-50	932615.750	1248142.900	1248142.900	33.832	33.832	0.303	2.089
p6	16-50	977799.400	1248142.900	1248142.900	27.648	27.648	0.164	1.039
p7	16-50	1010641.450	1248142.900	1248142.900	23.500	23.500	0.151	1.449
p8	16-50	1034976.970	1248142.900	1248142.900	20.596	20.596	0.379	1.138
p9	25-50	796648.440	1546761.575	1347029.813	94.159	69.087	0.262	2.527
p10	25-50	858109.320	1561761.575	1362029.813	82.000	58.725	0.502	1.913
p11	25-50	900760.110	1576761.575	1377029.813	75.048	52.874	1.670	1.880
p12	25-50	950608.420	1599261.575	1399529.813	68.236	47.225	0.271	2.115
p13	25-50	796648.440	1248142.900	1248142.900	56.674	56.674	0.190	1.980
p14	25-50	854704.200	1248142.900	1248142.900	46.032	46.032	0.659	1.478
p15	25-50	893782.110	1248142.900	1248142.900	39.647	39.647	0.737	1.170

p16	25-50	928941.750	1248142.900	1248142.900	34.362	34.362	0.192	1.092
p17	50-50	793439.560	2283329.775	1515406.013	187.776	90.992	0.309	1.576
p18	50-50	854900.450	2298329.775	1530406.013	168.842	79.016	0.347	1.295
p19	50-50	898266.080	2313329.775	1545406.013	157.533	72.043	0.481	1.642
p20	50-50	950608.430	2335829.775	1567906.013	145.719	64.937	0.321	1.872
p21	50-50	793439.560	1248142.900	1248142.900	57.308	57.308	0.220	1.029
p22	50-50	851495.320	1248142.900	1248142.900	46.582	46.582	0.241	1.019
p23	50-50	893076.710	1248142.900	1248142.900	39.758	39.758	0.221	1.168
p24	50-50	928941.750	1248142.900	1248142.900	34.362	34.362	0.226	1.102
p25	100-1000	19241056.930	41805566.140	27277413.170	117.273	41.767	19.802	8680.338
p26	100-1000	18438329.780	40569173.490	29655156.360	120.026	60.834	15.413	3393.579
p27	100-1000	17765201.950	38792572.920	29374254.150	118.363	65.347	18.321	4822.116
p28	100-1000	17160612.230	37495061.230	28778008.560	118.495	67.698	11.988	4970.128
p29	100-1000	13657464.230	37796619.930	19941008.780	176.747	46.008	27.998	9072.835
p30	100-1000	13362529.340	35237912.710	16928300.740	163.707	26.685	21.712	15105.428
p31	100-1000	13199213.190	33682207.220	16248911.040	155.183	23.105	29.851	11996.563
p32	100-1000	13083203.740	32396758.770	18490844.650	147.621	41.333	17.603	9384.492
p33	100-1000	11647410.500	34695475.230	17101122.740	197.881	46.823	38.465	15105.490
p34	100-1000	11570437.680	33233824.430	16291703.110	187.230	40.805	20.502	22156.194
p35	100-1000	11519169.780	31616521.650	15828285.410	174.469	37.408	25.759	18855.702
p36	100-1000	11505861.860	32092539.080	17788015.630	178.923	54.600	23.531	10358.103

Table 14: Computacional results for OR-Library Dataset - Metaheuristic Grasp and Local Search Shift

#	**|I|-|J|**	**Z***	**Z**	**Gap**	**Time Constructive**	**Time Local**
p1	16-50	932615.750	1075491.550	15.320	0.816	0.252
p2	16-50	977799.400	1067147.725	9.138	0.848	0.151
p3	16-50	1014099.610	1160166.938	14.404	0.797	0.093
p4	16-50	1053197.440	1087949.575	3.300	0.865	0.095
p5	16-50	932615.750	1248142.900	33.832	16.344	0.083
p6	16-50	977799.400	1248142.900	27.648	12.015	0.062
p7	16-50	1010641.450	1248142.900	23.500	10.465	0.044
p8	16-50	1034976.970	1248142.900	20.596	14.554	0.102
p9	25-50	796648.440	1055870.450	32.539	1.338	0.174
p10	25-50	858109.320	1035441.950	20.666	2.079	0.277
p11	25-50	900760.110	1063480.025	18.065	1.515	0.194
p12	25-50	950608.420	1070617.250	12.624	1.717	0.165
p13	25-50	796648.440	1248142.900	56.674	10.937	0.061
p14	25-50	854704.200	1248142.900	46.032	13.999	0.072
p15	25-50	893782.110	1248142.900	39.647	6.710	0.065
p16	25-50	928941.750	1248142.900	34.362	9.737	0.084
p17	50-50	793439.560	1182235.438	49.001	1.286	0.237
p18	50-50	854900.450	1185201.013	38.636	2.023	0.255

p19	50-50	898266.080	1089993.375	21.344	1.605	0.169
p20	50-50	950608.430	1055135.900	10.996	2.333	0.161
p21	50-50	793439.560	1248142.900	57.308	13.039	0.340
p22	50-50	851495.320	1248142.900	46.582	7.980	0.127
p23	50-50	893076.710	1248142.900	39.758	9.057	0.248
p24	50-50	928941.750	1248142.900	34.362	7.205	0.151
p25	100-1000	19241056.930	20878746.710	8.511	28.953	6.410
p26	100-1000	18438329.780	19485299.260	5.678	32.857	7.916
p27	100-1000	17765201.950	19839971.820	11.679	34.060	6.775
p28	100-1000	17160612.230	20138612.480	17.354	32.765	5.999
p29	100-1000	13657464.230	16616426.530	21.666	34.581	7.790
p30	100-1000	13362529.340	15397128.360	15.226	33.393	6.478
p31	100-1000	13199213.190	15279814.950	15.763	33.253	6.925
p32	100-1000	13083203.740	14708201.460	12.420	37.407	8.117
p33	100-1000	11647410.500	13494890.560	15.862	33.317	8.459
p34	100-1000	11570437.680	14679185.060	26.868	34.682	7.655
p35	100-1000	11519169.780	13957603.970	21.168	31.874	6.410
p36	100-1000	11505861.860	13679157.860	18.889	30.835	7.001

Table 15: Computacional results for OR-Library Dataset - Metaheuristic Grasp and Local Search Swap

#	**|I|-|J|**	**Z***	**Z**	**Gap**	**Time Constructive**	**Time Local**
p1	16-50	932615.750	1076132.750	15.389	1.011	2.327
p2	16-50	977799.400	1102983.375	12.803	1.210	1.763
p3	16-50	1014099.610	1112418.325	9.695	1.315	1.322
p4	16-50	1053197.440	1148293.288	9.029	1.209	1.321
p5	16-50	932615.750	1248142.900	33.832	1.199	0.741
p6	16-50	977799.400	1248142.900	27.648	1.319	0.867
p7	16-50	1010641.450	1248142.900	23.500	1.179	0.647
p8	16-50	1034976.970	1248142.900	20.596	1.168	0.642
p9	25-50	796648.440	1027442.288	28.971	1.532	1.229
p10	25-50	858109.320	1054239.350	22.856	2.681	2.738
p11	25-50	900760.110	1024970.775	13.790	1.142	1.366
p12	25-50	950608.420	1137877.750	19.700	1.157	1.300
p13	25-50	796648.440	1248142.900	56.674	1.389	0.634
p14	25-50	854704.200	1248142.900	46.032	1.394	0.622
p15	25-50	893782.110	1248142.900	39.647	1.548	0.810
p16	25-50	928941.750	1248142.900	34.362	1.359	0.758
p17	50-50	793439.560	1055039.675	32.970	1.678	1.605
p18	50-50	854900.450	1068878.513	25.030	1.853	1.322
p19	50-50	898266.080	1109581.663	23.525	2.083	2.104
p20	50-50	950608.430	1095688.425	15.262	1.569	1.348
p21	50-50	793439.560	1248142.900	57.308	1.635	0.853

p22	50-50	851495.320	1248142.900	46.582	3.419	1.015
p23	50-50	893076.710	1248142.900	39.758	3.105	1.720
p24	50-50	928941.750	1248142.900	34.362	1.718	0.704
p25	100-1000	19241056.930	22230570.230	15.537	34.619	6698.449
p26	100-1000	18438329.780	22187537.410	20.334	32.769	3971.241
p27	100-1000	17765201.950	21630882.960	21.760	33.986	3689.204
p28	100-1000	17160612.230	21582389.590	25.767	37.378	4276.824
p29	100-1000	13657464.230	16924047.030	23.918	47.865	7253.320
p30	100-1000	13362529.340	16698324.510	24.964	33.111	5442.093
p31	100-1000	13199213.190	16584445.840	25.647	32.297	5192.062
p32	100-1000	13083203.740	16496264.990	26.087	48.137	7445.724
p33	100-1000	11647410.500	14557857.140	24.988	34.481	8459.231
p34	100-1000	11570437.680	14129087.590	22.114	47.262	6586.693
p35	100-1000	11519169.780	14575394.420	26.532	33.506	7032.035
p36	100-1000	11505861.860	15244228.600	32.491	33.386	8202.839

4.4 Yang

Table 4 represents the Yang computational results. In this case, it appears that the number of customers and facilities is constant across the instances, so the computational time is always similar, managing to reach the optimal solution within the time limit of 20 minutes previously defined for Solver.

Table 16: Computacional results for Yang Dataset using the Exact Method

#	**|I|-|J|**	**Z***	**Z**	**Gap**	**Time**
p1	30-200	30181	30181	0	1199545
p2	30-200	28923	28925	0.007	1199753
p3	30-200	28131	28131	0	96080
p4	30-200	28152	28152	0	190352
p5	30-200	27646	27646	0	5500
p6	60-200	27977	28017	0.143	1199625
p7	60-200	29704	29861	0.529	1199632
p8	60-200	27993	28017	0.086	1199417
p9	60-200	27691	27691	0	776915
p10	60-200	29195	29269	0.254	1199575
p11	60-300	35648	35707	0.166	1199563
p12	60-300	35474	35474	0	410507
p13	60-300	33872	33930	0.171	1199825
p14	60-300	33096	33096	0	971309
p15	60-300	30918	30918	0	806722
p16	80-400	39318	39365	0.120	1200035
p17	80-400	37076	37254	0.480	1200421
p18	80-400	43859	44796	2.136	1200605
p19	80-400	37344	37344	0	701442

p20	80-400	43508	43692	0.423	1200736

Table 17: Computacional results for Yang Dataset - Heuristic constructive and Local Search Shift

#	|I|-|J|	Z*	Z Constructive	Z Local Search Shift	Gap Constructive	Gap Local Search Shift	Time Constructive	Time Local Search Shift
p1	30-200	30181	48559	41788	60.893	38.458	3.632	1.040
p2	30-200	28923	44502	43634	53.864	50.863	1.938	0.880
p3	30-200	28131	41371	37377	47.066	32.868	1.696	0.571
p4	30-200	28152	44962	39159	59.712	39.098	2.230	0.696
p5	30-200	27646	41862	38369	51.422	38.787	1.984	0.590
p6	60-200	27977	42737	39040	52.758	39.543	1.814	0.856
p7	60-200	29704	48047	42367	61.753	42.631	1.736	1.180
p8	60-200	27993	45865	38991	63.845	39.288	1.794	0.957
p9	60-200	27691	45749	40112	65.213	44.856	1.459	0.829
p10	60-200	29195	45542	40393	55.992	38.356	2.238	1.094
p11	60-300	35648	58202	53660	63.269	50.527	3.651	1.150
p12	60-300	35474	62920	52226	77.369	47.223	4.353	1.404
p13	60-300	33872	55519	49873	63.908	47.240	2.733	1.143
p14	60-300	33096	53009	52138	60.167	57.536	2.882	1.543
p15	60-300	30918	55231	50247	78.637	62.517	2.440	1.310
p16	80-400	39318	73655	66903	87.332	70.159	4.709	2.007
p17	80-400	37076	61331	59961	65.420	61.725	3.192	1.631
p18	80-400	43859	74421	69086	69.682	57.518	5.387	2.791
p19	80-400	37344	63975	53162	71.313	42.358	3.565	2.439
p20	80-400	43508	72847	71077	67.434	63.365	6.131	1.896

Table 18: Computacional results for Yang Dataset - Heuristic constructive and Local Search Swap

#	|I|-|J|	Z*	Z Constructive	Z Local Search Swap	Gap Constructive	Gap Local Search Swap	Time Constructive	Time Local Search Swap
p1	30-200	30181	48559	34961	60.893	15.838	3.632	107.232
p2	30-200	28923	44502	31831	53.864	10.054	1.938	151.399
p3	30-200	28131	41371	30978	47.066	10.121	1.696	136.480
p4	30-200	28152	44962	31038	59.712	10.251	2.230	117.415
p5	30-200	27646	41862	32160	51.422	16.328	1.984	84.428
p6	60-200	27977	42737	32173	52.758	14.998	1.814	129.180
p7	60-200	29704	48047	33590	61.753	13.082	1.736	118.552

p8	60-200	27993	45865	34423	63.845	22.970	1.794	90.404
p9	60-200	27691	45749	32733	65.213	18.208	1.459	108.903
p10	60-200	29195	45542	33921	55.992	16.188	2.238	115.113
p11	60-300	35648	58202	42416	63.269	18.986	3.651	348.717
p12	60-300	35474	62920	45382	77.369	27.930	4.353	280.341
p13	60-300	33872	55519	40412	63.908	19.308	2.733	292.737
p14	60-300	33096	53009	39023	60.167	17.909	2.882	302.826
p15	60-300	30918	55231	40078	78.637	29.627	2.440	285.930
p16	80-400	39318	73655	55745	87.332	41.780	4.709	713.423
p17	80-400	37076	61331	45293	65.420	22.163	3.192	1007.499
p18	80-400	43859	74421	52637	69.682	20.014	5.387	1029.903
p19	80-400	37344	63975	48165	71.313	28.977	3.565	349.365
p20	80-400	43508	72847	51470	67.434	18.300	6.131	872.419

Table 19: Computacional results for Yang Dataset - Metaheuristic Grasp and Local Search Shift

#	**|I|-|J|**	**Z***	**Z**	**Gap**	**Time Constructive**	**Time Local**
p1	30-200	30181	34284	13.595	3.987	0.646
p2	30-200	28923	32932	13.861	3.412	0.784
p3	30-200	28131	32015	13.807	2.736	0.851
p4	30-200	28152	32238	14.514	2.769	1.914
p5	30-200	27646	31060	12.349	3.413	0.883
p6	60-200	27977	33399	19.380	5.024	2.174
p7	60-200	29704	34364	15.688	7.096	1.252
p8	60-200	27993	34266	22.409	4.784	2.070
p9	60-200	27691	34699	25.308	7.053	0.990
p10	60-200	29195	34994	19.863	5.744	1.545
p11	60-300	35648	42130	18.183	10.415	1.737
p12	60-300	35474	43168	21.689	8.542	2.081
p13	60-300	33872	41104	21.351	6.829	1.393
p14	60-300	33096	39993	20.839	7.002	2.477
p15	60-300	30918	36267	17.301	6.385	1.483
p16	80-400	39318	48212	22.621	11.933	3.706
p17	80-400	37076	43424	17.122	16.625	3.780
p18	80-400	43859	54062	23.263	17.779	3.566
p19	80-400	37344	44391	18.871	16.355	2.804
p20	80-400	43508	53266	22.428	16.998	4.248

Table 20: Computacional results for Yang Dataset - Metaheuristic Grasp and Local Search Swap

#	|I|-|J|	Z*	Z	Gap	Time Constructive	Time Local
p1	30-200	30181	34144	13.131	3.044	61.190
p2	30-200	28923	32298	11.669	2.696	52.688
p3	30-200	28131	31504	11.990	2.804	72.403
p4	30-200	28152	31330	11.289	2.732	76.333
p5	30-200	27646	31400	13.579	3.445	57.628
p6	60-200	27977	33230	18.776	4.820	46.437
p7	60-200	29704	36027	21.287	4.121	31.485
p8	60-200	27993	33723	20.469	4.955	76.475
p9	60-200	27691	33817	22.123	5.796	71.127
p10	60-200	29195	34945	19.695	6.843	35.712
p11	60-300	35648	42781	20.010	6.871	139.391
p12	60-300	35474	41744	17.675	6.219	151.483
p13	60-300	33872	40105	18.402	5.872	109.712
p14	60-300	33096	40991	23.855	6.054	146.242
p15	60-300	30918	36067	16.654	6.076	116.529
p16	80-400	39318	47196	20.037	10.830	254.780
p17	80-400	37076	42762	15.336	10.825	352.647
p18	80-400	43859	54101	23.352	10.212	345.001
p19	80-400	37344	44198	18.354	10.239	293.409
p20	80-400	43508	53100	22.047	10.246	300.759

4.5 TBED1

Table 5,6,7,8 and 9 represents the Yang computational results. In this case, it appears that the number of customers and facilities is constant across the instances, so the computational time is always similar, managing to reach the optimal solution within the time limit of 20 minutes previously defined for Solver. Due to the high complexity, the results obtained present a level below the others.

Table 21: Computacional results for Yang Dataset 5_1 using the Exact Method

#	|I|-|J|	Z*	Z	Gap	Time
p1	300-300	16350	17306.670	5.528	1200723
p2	300-300	15948	17048.550	6.4553	1200829
p3	300-300	15474	16170.372	4.306	1200769
p4	300-300	17989	19056.291	5.600	1200526
p5	300-300	18037	19562.986	7.800	1200798
p6	300-300	11251	11441.672	1.666	1200802
p7	300-300	11392	11635.458	2.0924	1200782
p8	300-300	11449	11449.671	0.00585	1173781
p9	300-300	10932	11016.263	0.765	1200790
p10	300-300	11232	12703.828	11.586	1264759
p11	300-300	10046	16446.872	38.918	1938560
p12	300-300	9359	9359.641	0.007	1007999

p13	300-300	10103	10121.376	0.182	1200833
p14	300-300	9738	9738.045	0.0004	614627
p15	300-300	9902	9902.261	0.003	421362
p16	300-300	9168	9168.0795	0.001	119991
p17	300-300	9181	9181.0652	0.001	101342
p18	300-300	9581	9581.951	0.009	148927
p19	300-300	9062	9062.157	0.002	171151
p20	300-300	9078	9078.219	0.002	71411

Table 22: Computacional results for Yang Dataset 5_2 using the Exact Method

#	|I|-|J|	Z*	Z	Gap	Time
p1	300-1500	154999	154999.191	0.0001	638281
p2	300-1500	159438	159439.305	0.00082	397894
p3	300-1500	157300	157300.151	≈ 0	617046
p4	300-1500	157796	157796.280	0.0001	1100958
p5	300-1500	161306	161305.972	≈ 0	431350
p6	300-1500	156669	156667.309	0.001	225815
p7	300-1500	157031	157032.714	0.001	180447
p8	300-1500	157802	157796.208	0.003	193796
p9	300-1500	156968	156973.235	0.003	214597
p10	300-1500	157764	157762.710	0.0008	197973
p11	300-1500	150015	150015.126	≈ 0	147569
p12	300-1500	154937	154937.669	0.0004	291069
p13	300-1500	151608	151611.503	0.002	135718
p14	300-1500	151848	151848.646	0.0004	203121
p15	300-1500	156480	156480.887	≈ 0	199525
p16	300-1500	155495	155493.774	≈ 0	108830
p17	300-1500	156038	156040.116	0.00136	140478
p18	300-1500	156799	156790.752	0.005	116782
p19	300-1500	155947	155954.060	0.005	123410
p20	300-1500	156426	156426.137	≈ 0	169604

Table 23: Computacional results for Yang Dataset 5_3 using the Exact Method

#	|I|-|J|	Z*	Z	Gap	Time
p1	500-500	26412	29141.69276	2729.693	1202312
p2	500-500	28130	29632.48622	1502.486	1202598
p3	500-500	27904	29479.61162	1575.612	1202564
p4	500-500	28159	43587.19463	15428.195	1206054
p5	500-500	24702	26116.00386	1414.004	1203357
p6	500-500	15756	16686.54108	930.541	1203747
p7	500-500	16109	24254.64761	8145.648	1203888

p8	500-500	16041	16898.04361	857.044	1204523
p9	500-500	16327	22689.12994	6362.130	4092273
p10	500-500	15815	16652.44086	837.441	1203844
p11	500-500	13497	13760.55255	263.5535	1203611
p12	500-500	14675	15304.44344	629.443	1203514
p13	500-500	13666	13802.71378	136.714	1202349
p14	500-500	13629	13654.30573	25.306	1202445
p15	500-500	13896	14156.64132	260.641	1202501
p16	500-500	12618	12625.66203	7.662	1202792
p17	500-500	13386	13391.12149	5.122	1202685
p18	500-500	12852	12852.52183	0.522	835737
p19	500-500	13521	13536.03792	15.038	1202802
p20	500-500	12362	12362.19543	0.195	559533

Table 24: Computacional results for Yang Dataset 5_4 using the Exact Method

#	**|I|-|J|**	**Z***	**Z**	**Gap**	**Time**
p1	700-700	36905	58554.57046	21649.571	1249846
p2	700-700	34311	55974.29195	21663.292	1281569
p3	700-700	34294	37048.82777	2754.828	1207323
p4	700-700	38090	56713.80277	18623.803	1259437
p5	700-700	37802	60338.60064	22536.601	1740472
p6	700-700	19910	28986.0763	9076.076	2113997
p7	700-700	21297	30255.21124	8958.211	1216531
p8	700-700	20659	27573.79221	6914.792	1280475
p9	700-700	20979	32847.24299	11868.243	1278363
p10	700-700	22055	32207.89235	10152.892	1331184
p11	700-700	17120	21902.52715	4782.527	1239796
p12	700-700	18130	18807.10627	677.106	1205408
p13	700-700	17239	17373.61906	134.619	1204946
p14	700-700	17337	17621.63772	284.638	1204970
p15	700-700	18145	22794.73367	4649.734	1296458
p16	700-700	16029	16229.26021	200.260	1205245
p17	700-700	16199	21223.39753	5024.398	1217422
p18	700-700	16443	16587.7614	144.761	1205114
p19	700-700	16399	16697.35147	298.352	1205482
p20	700-700	15434	15663.03311	229.033	1204189

Table 25: Computacional results for Yang Dataset 5_5 using the Exact Method

#	**|I|-|J|**	**Z***	**Z**	**Gap**	**Time**
p1	1000-1000	49509.81	83483.593	68.620	1209438
p2	1000-1000	50688.57	79663.223	57.162	1199326

p3	1000-1000	47202.64	82876.669	75.576	1224480
p4	1000-1000	48868.54	83461.537	70.789	1217321
p5	1000-1000	50743.54	80137.435	57.926	1214934
p6	1000-1000	27823.84	39343.070	41.400	1217917
p7	1000-1000	27252.32	41506.506	52.304	1222912
p8	1000-1000	27375.37	36596.560	33.684	1223355
p9	1000-1000	26857.09	40176.389	49.593	1223243
p10	1000-1000	27186.99	40409.649	48.636	1224145
p11	1000-1000	22180.33	35390.451	59.558	1245510
p12	1000-1000	22160.39	34387.905	55.177	1224612
p13	1000-1000	22657.09	32867.315	45.064	1226032
p14	1000-1000	22312.01	33610.615	50.639	1234637
p15	1000-1000	22629.44	36917.431	63.139	1231019
p16	1000-1000	21331.81	33271.691	55.972	3016002
p17	1000-1000	21188.89	59104.777	178.942	1234328
p18	1000-1000	20713.43	43033.769	107.757	1246951
p19	1000-1000	20537.45	35217.427	71.479	1244970
p20	1000-1000	21560.86	45672.311	111.830	1240260

Table 26: Computacional results for TBED1 Dataset - Heuristic constructive and Local Search Shift

#	|I|-|J|	Z*	Z Constructive	Z Local Search Shift	Gap Constructive	Gap Local Search Shift	Time Constructive	Time Local Search Shift
p1	300-300	16350.660	41635.647	35939.406	154.642	119.804	13.685	5.388
p2	300-300	15948.440	39446.159	35074.530	147.336	119.925	11.090	7.600
p3	300-300	15474.840	39702.112	35354.265	156.559	128.463	12.103	5.373
p4	300-300	17989.970	43259.377	42117.008	140.464	134.114	11.297	5.369
p5	300-300	18037.610	42948.067	36734.820	138.103	103.657	11.139	5.348
p6	300-300	11251.190	37683.814	35725.806	234.932	217.529	5.603	4.811
p7	300-300	11392.520	35329.307	26168.439	210.110	129.698	6.257	7.041
p8	300-300	11449.670	35136.514	29893.086	206.878	161.083	8.268	4.707
p9	300-300	10932.880	35844.139	29261.084	227.856	167.643	6.060	5.026
p10	300-300	11232.770	36707.542	32052.986	226.790	185.352	7.407	5.488
p11	300-300	10046.940	31636.534	24960.873	214.887	148.443	5.922	4.188
p12	300-300	9359.640	32480.626	27710.837	247.029	196.067	4.704	4.481
p13	300-300	10103.490	34694.090	26591.236	243.387	163.189	4.703	4.618
p14	300-300	9738.050	35996.615	33589.032	269.649	244.926	3.914	4.295
p15	300-300	9902.260	32340.334	28794.464	226.595	190.787	5.377	6.908
p16	300-300	9168.080	28793.314	23839.829	214.060	160.031	4.350	7.131
p17	300-300	9181.070	33359.443	29428.157	263.350	220.531	3.461	4.316
p18	300-300	9581.950	30189.896	26778.294	215.070	179.466	4.664	4.440
p19	300-300	9062.160	33373.406	21996.107	268.272	142.725	3.485	5.891

p20	300-300	9078.220	31826.367	23527.027	250.579	159.159	4.789	8.380
p21	300-1500	154999.140	1452082.278	1237850.567	836.832	698.618	232.709	28.739
p22	300-1500	159438.600	1650610.692	1087478.868	935.264	582.067	292.570	34.126
p23	300-1500	157300.150	1562826.862	1264534.064	893.532	703.899	188.700	33.388
p24	300-1500	157796.280	1580757.413	1152982.062	901.771	630.678	279.810	46.393
p25	300-1500	161306.000	1520635.046	1270882.481	842.702	687.871	256.436	41.486
p26	300-1500	156669.280	1504874.812	1474801.842	860.542	841.347	143.618	26.726
p27	300-1500	157031.550	1485955.818	1237457.380	846.279	688.031	123.544	35.939
p28	300-1500	157802.830	1544662.183	993047.761	878.856	529.297	137.298	38.321
p29	300-1500	156968.460	1586474.985	1096341.842	910.697	598.447	129.345	34.474
p30	300-1500	157764.390	1513498.290	1258782.127	859.341	697.887	144.039	39.320
p31	300-1500	150015.130	1412938.707	1289750.439	841.864	759.747	98.039	31.871
p32	300-1500	154937.670	1556442.958	1150050.942	904.561	642.267	79.824	28.155
p33	300-1500	151608.420	1567916.336	1271626.650	934.188	738.757	100.263	37.485
p34	300-1500	151848.050	1559663.459	1122139.571	927.121	638.988	73.256	25.316
p35	300-1500	156480.890	1479069.453	1071851.227	845.208	584.973	112.700	40.557
p36	300-1500	155495.620	1559290.877	1552093.365	902.788	898.159	60.691	21.114
p37	300-1500	156038.040	1472890.739	1172805.169	843.931	651.615	65.153	35.176
p38	300-1500	156799.930	1521807.207	1200698.449	870.541	665.752	76.391	35.529
p39	300-1500	155947.130	1507856.803	1135332.375	866.903	628.024	65.519	31.942
p40	300-1500	156426.140	1448411.471	1239429.165	825.940	692.341	55.116	25.568
p41	500-500	26412.41	68340.356	66218.339	158.743	150.709	39.179	18.490
p42	500-500	28130.74	71961.084	67135.415	155.809	138.655	58.740	20.454
p43	500-500	27904.51	69762.669	64631.636	150.005	131.617	57.094	21.011
p44	500-500	28159.03	71052.029	69857.661	152.324	148.083	44.660	25.523
p45	500-500	24702.77	67163.163	66135.695	171.885	167.726	60.447	24.059
p46	500-500	15756.82	58096.884	45908.692	268.709	191.358	28.532	23.028
p47	500-500	16109.28	59808.619	45380.377	271.268	181.703	30.504	23.095
p48	500-500	16041.73	57287.393	52172.332	257.115	225.229	25.776	18.172
p49	500-500	16327.71	55001.203	41756.589	236.858	155.741	29.106	23.956
p50	500-500	15815.13	55349.629	43443.843	249.979	174.698	34.569	18.556
p51	500-500	13497.71	54680.695	45456.695	305.111	236.773	18.296	21.784
p52	500-500	14675.02	56870.350	48776.867	287.532	232.380	20.384	17.997
p53	500-500	13666.25	53621.004	50631.998	292.361	270.489	24.208	19.090
p54	500-500	13629.54	54493.607	49279.230	299.820	261.562	17.397	16.325
p55	500-500	13896.76	52500.029	44049.571	277.786	216.977	23.318	22.570
p56	500-500	12618.68	50023.475	49471.885	296.424	292.053	16.332	21.037
p57	500-500	13386.17	58462.566	43562.946	336.739	225.432	14.716	15.302
p58	500-500	12852.52	51037.184	47594.756	297.099	270.315	18.199	18.066
p59	500-500	13521.52	53443.981	43255.651	295.251	219.902	13.733	14.656
p60	500-500	12362.26	54101.732	47632.700	337.636	285.307	9.572	21.043
p61	700-700	36905.930	104392.368	86613.144	182.861	134.686	126.584	33.029
p62	700-700	34311.710	96962.616	84101.918	182.593	145.111	104.215	32.755
p63	700-700	34294.630	100711.783	99197.702	193.666	189.251	122.629	35.900
p64	700-700	38090.900	103171.936	97439.615	170.857	155.808	122.881	38.863
p65	700-700	37802.100	96619.441	92652.640	155.593	145.099	138.787	35.021

p66	700-700	19910.670	81930.732	67264.530	311.492	237.832	63.845	27.391
p67	700-700	21297.300	82179.629	76032.309	285.869	257.004	66.510	29.412
p68	700-700	20659.960	81296.690	69952.694	293.499	238.591	61.144	29.773
p69	700-700	20979.880	81186.650	70738.953	286.974	237.175	62.414	32.417
p70	700-700	22055.410	87032.412	83962.034	294.608	280.687	57.510	27.135
p71	700-700	17120.150	78929.946	77270.822	361.035	351.344	46.959	32.691
p72	700-700	18130.420	81799.808	63801.944	351.174	251.905	49.649	31.176
p73	700-700	17239.960	70878.739	51039.622	311.131	196.054	31.733	26.895
p74	700-700	17337.630	75094.652	71096.842	333.131	310.072	42.456	27.335
p75	700-700	18145.490	82554.247	73600.095	354.957	305.611	34.285	33.323
p76	700-700	16029.550	74705.580	56744.553	366.049	253.999	25.193	25.452
p77	700-700	16199.550	79528.798	51164.632	390.932	215.840	30.308	38.789
p78	700-700	16443.070	78568.468	63037.460	377.821	283.368	35.028	38.563
p79	700-700	16399.790	77659.477	56386.144	373.539	243.822	29.227	38.813
p80	700-700	15434.210	76463.500	71907.987	395.416	365.900	26.867	26.231
p81	1000-1000	49509.810	139357.316	121138.335	181.474	144.675	308.292	92.844
p82	1000-1000	50688.570	143164.132	135545.258	182.439	167.408	335.711	82.009
p83	1000-1000	47202.640	141711.786	139945.555	200.220	196.478	294.711	61.695
p84	1000-1000	48868.540	140577.389	131593.798	187.664	169.281	314.300	76.773
p85	1000-1000	50743.540	141275.022	130311.425	178.410	156.804	327.002	76.288
p86	1000-1000	27823.840	122445.542	99230.917	340.074	256.640	144.050	103.051
p87	1000-1000	27252.320	116438.840	96996.282	327.262	255.919	171.709	83.759
p88	1000-1000	27375.370	112975.808	104250.481	312.691	280.819	192.155	96.544
p89	1000-1000	26857.090	115737.771	85262.659	330.939	217.468	203.829	87.330
p90	1000-1000	27186.990	115491.461	81189.284	324.804	198.633	219.866	83.625
p91	1000-1000	22180.330	108672.882	105716.706	389.952	376.624	97.241	57.823
p92	1000-1000	22160.390	113288.625	84289.076	411.221	280.359	121.254	54.472
p93	1000-1000	22657.090	115703.554	81563.457	410.673	259.991	91.982	63.852
p94	1000-1000	22312.010	111210.263	85168.444	398.432	281.716	115.097	81.492
p95	1000-1000	22629.440	109933.394	88657.469	385.798	291.779	95.903	58.490
p96	1000-1000	21331.810	111506.956	83167.036	422.726	289.873	84.089	88.300
p97	1000-1000	21188.890	107559.632	84877.618	407.623	300.576	96.609	72.466
p98	1000-1000	20713.430	105720.302	76736.547	410.395	270.468	75.182	57.456
p99	1000-1000	20537.450	108213.375	79802.897	426.908	288.573	90.206	69.030
p100	1000-1000	21560.860	109447.628	76705.274	407.622	255.762	95.694	69.582

Table 27: Computacional results for TBED1 Dataset - Heuristic constructive and Local Search Swap

#	|I|-|J|	Z*	Z Constructive	Z Local Search Swap	Gap Constructive	Gap Local Search Swap	Time Constructive	Time Local Search Swap
p1	300-300	16350.660	41635.647	22480.559	154.642	37.490	13.685	621.543
p2	300-300	15948.440	39446.159	19786.220	147.336	24.064	11.090	720.053

p3	300-300	15474.840	39702.112	19451.008	156.559	25.694	12.103	765.232
p4	300-300	17989.970	43259.377	21978.611	140.464	22.171	11.297	840.831
p5	300-300	18037.610	42948.067	22817.622	138.103	26.500	11.139	639.311
p6	300-300	11251.190	37683.814	17127.835	234.932	52.231	5.603	673.910
p7	300-300	11392.520	35329.307	15653.062	210.110	37.398	6.257	521.613
p8	300-300	11449.670	35136.514	16195.666	206.878	41.451	8.268	556.206
p9	300-300	10932.880	35844.139	16510.534	227.856	51.017	6.060	578.306
p10	300-300	11232.770	36707.542	17236.067	226.790	53.444	7.407	528.337
p11	300-300	10046.940	31636.534	18857.516	214.887	87.694	5.922	328.275
p12	300-300	9359.640	32480.626	13408.640	247.029	43.260	4.704	484.914
p13	300-300	10103.490	34694.090	17703.307	243.387	75.220	4.703	404.307
p14	300-300	9738.050	35996.615	17465.803	269.649	79.356	3.914	503.947
p15	300-300	9902.260	32340.334	18462.898	226.595	86.451	5.377	392.564
p16	300-300	9168.080	28793.314	13801.693	214.060	50.541	4.350	400.962
p17	300-300	9181.070	33359.443	17388.705	263.350	89.397	3.461	450.661
p18	300-300	9581.950	30189.896	15422.579	215.070	60.954	4.664	435.471
p19	300-300	9062.160	33373.406	16051.646	268.272	77.128	3.485	289.036
p20	300-300	9078.220	31826.367	14421.712	250.579	58.861	4.789	352.931
p21	300-1500	154999.140	1452082.278	420525.533	836.832	171.308	232.709	127071.574
p22	300-1500	159438.600	1650610.692	468365.811	935.264	193.759	292.570	102176.496
p23	300-1500	157300.150	1562826.862	531624.269	893.532	237.968	188.700	88968.490
p24	300-1500	157796.280	1580757.413	572930.116	901.771	263.082	279.810	108948.068
p25	300-1500	161306.000	1520635.046	481135.557	842.702	198.275	256.436	132175.172
p26	300-1500	156669.280	1504874.812	556597.269	860.542	255.269	143.618	105382.231
p27	300-1500	157031.550	1485955.818	773774.900	846.279	392.751	123.544	88285.725
p28	300-1500	157802.830	1544662.183	526418.778	878.856	233.593	137.298	63100.229
p29	300-1500	156968.460	1586474.985	727374.219	910.697	363.389	129.345	66627.103
p30	300-1500	157764.390	1513498.290	599640.755	859.341	280.086	144.039	94414.811
p31	300-1500	150015.130	1412938.707	811131.567	841.864	440.700	98.039	84399.312
p32	300-1500	154937.670	1556442.958	811480.307	904.561	423.746	79.824	54252.276
p33	300-1500	151608.420	1567916.336	683436.338	934.188	350.790	100.263	70572.489
p34	300-1500	151848.050	1559663.459	652045.408	927.121	329.407	73.256	64993.781
p35	300-1500	156480.890	1479069.453	689540.248	845.208	340.655	112.701	64095.856
p36	300-1500	155495.620	1559290.877	727852.159	902.788	368.085	60.691	89394.710
p37	300-1500	156038.040	1472890.739	915415.912	843.931	486.662	65.153	45844.248
p38	300-1500	156799.930	1521807.207	712776.422	870.541	354.577	76.391	53454.366
p39	300-1500	155947.130	1507856.803	724276.528	866.903	364.437	65.519	64394.111
p40	300-1500	156426.140	1448411.471	694199.912	825.940	343.788	55.116	64113.479
p41	500-500	26412.410	68340.356	33344.460	158.743	26.245	39.179	4784.733
p42	500-500	28130.740	71961.084	36499.049	155.809	29.748	58.740	4885.779
p43	500-500	27904.510	69762.669	35058.619	150.005	25.638	57.094	4985.897
p44	500-500	28159.030	71052.029	34337.063	152.324	21.940	44.660	5664.574
p45	500-500	24702.770	67163.163	30787.585	171.885	24.632	60.447	5122.923
p46	500-500	15756.820	58096.884	28054.193	268.709	78.045	28.532	3424.845
p47	500-500	16109.280	59808.619	25351.976	271.268	57.375	30.504	3085.926
p48	500-500	16041.730	57287.393	24920.182	257.115	55.346	25.776	4588.513

p49	500-500	16327.710	55001.203	25478.788	236.858	56.046	29.106	3657.021
p50	500-500	15815.130	55349.629	25977.561	249.979	64.258	34.569	3238.430
p51	500-500	13497.710	54680.695	25322.694	305.111	87.607	18.296	3386.353
p52	500-500	14675.020	56870.350	24446.544	287.532	66.586	20.384	3449.421
p53	500-500	13666.250	53621.004	22953.836	292.361	67.960	24.208	4511.569
p54	500-500	13629.540	54493.607	22138.702	299.820	62.432	17.397	3764.951
p55	500-500	13896.760	52500.029	22650.984	277.786	62.995	23.318	3276.442
p56	500-500	12618.680	50023.475	28169.305	296.424	123.235	16.332	2996.742
p57	500-500	13386.170	58462.566	22596.983	336.739	68.808	14.716	1923.932
p58	500-500	12852.520	51037.184	23114.927	297.099	79.847	18.199	2872.723
p59	500-500	13521.520	53443.981	23443.956	295.251	73.383	13.733	2455.547
p60	500-500	12362.260	54101.732	24651.677	337.636	99.411	9.572	2445.044
p61	700-700	36905.930	104392.368	46792.583	182.861	26.789	126.584	9766.682
p62	700-700	34311.710	96962.616	43900.727	182.593	27.947	104.215	10631.309
p63	700-700	34294.630	100711.783	45060.387	193.666	31.392	122.629	13255.815
p64	700-700	38090.900	103171.936	47128.569	170.857	23.727	122.881	12746.520
p65	700-700	37802.100	96619.441	45916.375	155.593	21.465	138.787	13022.511
p66	700-700	19910.670	81930.732	30676.340	311.492	54.070	63.845	8774.574
p67	700-700	21297.300	82179.629	34822.282	285.869	63.506	66.510	10926.959
p68	700-700	20659.960	81296.690	33767.160	293.499	63.443	61.144	7041.392
p69	700-700	20979.880	81186.650	31292.012	286.974	49.152	62.414	9779.069
p70	700-700	22055.410	87032.412	38443.089	294.608	74.302	57.510	10247.428
p71	700-700	17120.150	78929.946	33731.788	361.035	97.030	46.959	9772.071
p72	700-700	18130.420	81799.808	28357.121	351.174	56.406	49.649	8340.647
p73	700-700	17239.960	70878.739	30382.078	311.131	76.231	31.733	7250.470
p74	700-700	17337.630	75094.652	32055.156	333.131	84.888	42.456	9130.555
p75	700-700	18145.490	82554.247	36528.097	354.957	101.307	34.285	8839.468
p76	700-700	16029.550	74705.580	26783.436	366.049	67.088	25.193	6846.056
p77	700-700	16199.550	79528.798	28158.605	390.932	73.823	30.308	5525.782
p78	700-700	16443.070	78568.468	33422.948	377.821	103.265	35.028	5605.924
p79	700-700	16399.790	77659.477	35541.007	373.539	116.716	29.227	6091.832
p80	700-700	15434.210	76463.500	33250.755	395.416	115.435	26.867	7950.170
p81	1000-1000	49509.810	139357.316	61806.275	181.474	24.836	308.293	38395.939
p82	1000-1000	50688.570	143164.132	65371.633	182.439	28.967	335.711	37702.250
p83	1000-1000	47202.640	141711.786	60383.516	200.220	27.924	294.711	40877.592
p84	1000-1000	48868.540	140577.389	60150.324	187.664	23.086	314.300	43018.452
p85	1000-1000	50743.540	141275.022	63886.519	178.410	25.901	327.002	40357.245
p86	1000-1000	27823.840	122445.542	41280.832	340.074	48.365	144.050	32071.296
p87	1000-1000	27252.320	116438.840	39945.144	327.262	46.575	171.709	33311.508
p88	1000-1000	27375.370	112975.808	40594.581	312.691	48.289	192.155	51276.805
p89	1000-1000	26857.090	115737.771	38720.327	330.939	44.172	203.829	34954.672
p90	1000-1000	27186.990	115491.461	41438.467	324.804	52.420	219.866	28548.130
p91	1000-1000	22180.330	108672.882	38059.046	389.952	71.589	97.241	29020.729
p92	1000-1000	22160.390	113288.625	37633.676	411.221	69.824	121.254	25161.314
p93	1000-1000	22657.090	115703.554	36975.737	410.673	63.197	91.982	27301.026
p94	1000-1000	22312.010	111210.263	37744.215	398.432	69.165	115.097	24849.880

p95	1000-1000	22629.440	109933.394	33935.760	385.798	49.963	95.903	29633.559
p96	1000-1000	21331.810	111506.956	36335.717	422.726	70.336	84.089	22163.472
p97	1000-1000	21188.890	107559.632	39622.689	407.623	86.997	96.609	21928.496
p98	1000-1000	20713.430	105720.302	34656.501	410.395	67.314	75.182	22319.340
p99	1000-1000	20537.450	108213.375	44315.048	426.908	115.777	90.206	18893.122
p100	1000-1000	21560.860	109447.628	45789.809	407.622	112.375	95.694	21389.460

Table 28: Computacional results for TBED1 Dataset - Metaheuristic Grasp and Local Search Shift

#	|I|-|J|	Z*	Z	Gap	Time Constructive	Time Local
p1	300-300	16350.660	25822.219	57.928	26.572	168.727
p2	300-300	15948.440	22511.652	41.153	27.581	133.213
p3	300-300	15474.840	22447.633	45.059	38.432	200.134
p4	300-300	17989.970	26955.555	49.837	27.258	135.434
p5	300-300	18037.610	26737.306	48.231	27.725	250.395
p6	300-300	11251.190	16613.613	47.661	28.619	208.401
p7	300-300	11392.520	16823.266	47.669	39.994	193.429
p8	300-300	11449.670	17250.255	50.662	33.672	156.303
p9	300-300	10932.880	15424.626	41.085	27.326	175.037
p10	300-300	11232.770	16317.849	45.270	32.302	134.903
p11	300-300	10046.940	14852.040	47.827	31.665	177.449
p12	300-300	9359.640	14323.308	53.033	28.076	144.001
p13	300-300	10103.490	16177.020	60.113	27.782	146.376
p14	300-300	9738.050	14172.787	45.540	43.884	225.713
p15	300-300	9902.260	14939.843	50.873	28.441	184.397
p16	300-300	9168.080	13524.333	47.515	27.895	134.536
p17	300-300	9181.070	13180.293	43.559	28.025	124.865
p18	300-300	9581.950	13222.597	37.995	27.898	157.081
p19	300-300	9062.160	11274.475	24.413	28.392	163.548
p20	300-300	9078.220	13779.074	51.782	28.876	171.164
p21	300-1500	154999.140	299329.029	93.117	195.195	25634.740
p22	300-1500	159438.600	315891.331	98.127	169.455	27419.727
p23	300-1500	157300.150	301647.790	91.766	195.912	17591.896
p24	300-1500	157796.280	316704.241	100.705	200.911	23018.875
p25	300-1500	161306.000	310070.003	92.225	149.071	14904.745
p26	300-1500	156669.280	374835.218	139.253	136.583	20844.327
p27	300-1500	157031.550	372180.716	137.010	146.063	14244.162
p28	300-1500	157802.830	362745.439	129.873	142.344	17408.796
p29	300-1500	156968.460	382511.374	143.687	152.969	21126.849
p30	300-1500	157764.390	365428.274	131.629	146.288	19389.502
p31	300-1500	150015.130	431839.586	187.864	201.344	16489.844
p32	300-1500	154937.670	423735.031	173.487	164.381	19968.718
p33	300-1500	151608.420	389722.584	157.059	180.828	15419.216

p34	300-1500	151848.050	429719.832	182.993	147.771	18678.797
p35	300-1500	156480.890	401626.661	156.662	144.355	18489.781
p36	300-1500	155495.620	471226.139	203.048	143.698	9424.463
p37	300-1500	156038.040	436266.030	179.590	198.638	16557.664
p38	300-1500	156799.930	443052.599	182.559	222.832	17445.585
p39	300-1500	155947.130	440196.497	182.273	162.233	19188.692
p40	300-1500	156426.140	469069.445	199.866	217.829	22897.558
p41	500-500	26412.410	38640.160	46.295	81.291	573.494
p42	500-500	28130.740	38195.011	35.777	73.915	794.440
p43	500-500	27904.510	39800.077	42.630	90.103	734.518
p44	500-500	28159.030	40154.292	42.598	71.686	616.805
p45	500-500	24702.770	35139.547	42.249	73.498	669.414
p46	500-500	15756.820	22702.830	44.083	71.967	619.579
p47	500-500	16109.280	24878.014	54.433	105.986	1174.323
p48	500-500	16041.730	25111.594	56.539	106.949	596.770
p49	500-500	16327.710	25609.708	56.848	73.533	1007.124
p50	500-500	15815.130	24837.126	57.047	74.430	573.687
p51	500-500	13497.710	19517.744	44.600	74.227	620.730
p52	500-500	14675.020	23542.671	60.427	74.437	705.069
p53	500-500	13666.250	20852.921	52.587	74.619	711.122
p54	500-500	13629.540	21625.880	58.669	108.856	582.458
p55	500-500	13896.760	23444.524	68.705	72.212	575.266
p56	500-500	12618.680	21213.997	68.116	71.928	602.308
p57	500-500	13386.170	20057.991	49.841	101.064	748.744
p58	500-500	12852.520	20064.042	56.110	71.937	613.122
p59	500-500	13521.520	20088.457	48.567	77.487	645.681
p61	700-700	36905.930	55771.810	51.119	132.335	2865.973
p62	700-700	34311.710	51476.808	50.027	134.335	1899.775
p63	700-700	34294.630	49852.457	45.365	131.084	1608.120
p64	700-700	38090.900	56616.012	48.634	134.111	2007.726
p65	700-700	37802.100	57136.728	51.147	170.982	1620.760
p66	700-700	19910.670	29601.835	48.673	134.429	1894.064
p67	700-700	21297.300	35001.771	64.348	140.349	3024.405
p68	700-700	20659.960	33201.769	60.706	200.003	1438.837
p69	700-700	20979.880	32182.787	53.398	160.856	1420.859
p70	700-700	22055.410	34589.188	56.829	134.104	2158.330
p71	700-700	17120.150	27929.909	63.141	203.326	1947.053
p72	700-700	18130.420	27356.974	50.890	134.637	1723.650
p73	700-700	17239.960	28767.279	66.864	136.800	1837.889
p74	700-700	17337.630	25161.841	45.128	136.674	1985.348
p75	700-700	18145.490	28054.036	54.606	135.506	1736.524
p76	700-700	16029.550	23933.805	49.311	156.636	1374.640
p77	700-700	16199.550	24543.956	51.510	133.987	1640.140
p78	700-700	16443.070	24837.293	51.050	136.130	1728.609
p79	700-700	16399.790	25310.310	54.333	145.530	1895.794
p80	700-700	15434.210	22747.815	47.386	160.269	2042.824

p81	1000-1000	49509.810	75390.464	52.274	290.828	5089.326
p82	1000-1000	50688.570	75589.559	49.125	257.970	4794.806
p83	1000-1000	47202.640	76366.845	61.785	257.301	5419.688
p84	1000-1000	48868.540	70836.700	44.954	260.759	5254.462
p85	1000-1000	50743.540	73494.227	44.835	260.250	5100.095
p86	1000-1000	27823.840	42937.054	54.317	262.451	4125.918
p87	1000-1000	27252.320	42484.820	55.894	261.530	5023.458
p88	1000-1000	27375.370	44176.640	61.374	262.534	5286.898
p89	1000-1000	26857.090	39705.440	47.840	258.991	5848.190
p90	1000-1000	27186.990	41930.562	54.230	374.650	4459.441
p91	1000-1000	22180.330	35561.127	60.327	358.765	6990.890
p92	1000-1000	22160.390	35459.292	60.012	272.259	6693.192
p93	1000-1000	22657.090	38517.589	70.002	279.566	4687.628
p94	1000-1000	22312.010	36185.887	62.181	282.849	7852.925
p95	1000-1000	22629.440	34407.159	52.046	507.852	10530.856
p96	1000-1000	21331.810	32835.263	53.926	447.327	5631.951
p97	1000-1000	21188.890	33170.480	56.547	311.142	4178.748
p98	1000-1000	20713.430	33069.408	59.652	333.731	5051.689
p99	1000-1000	20537.450	31608.484	53.907	270.964	4156.925
p100	1000-1000	21560.860	35415.763	64.260	267.835	4360.902

Table 29: Computacional results for TBED1 Dataset - Metaheuristic Grasp and Local Search Swap

#	**|I|-|J|**	**Z***	**Z**	**Gap**	**Time Constructive**	**Time Local**
p1	300-300	16350.660	25731.434	57.372	41.228	227.515
p2	300-300	15948.440	21732.683	36.268	37.512	190.392
p3	300-300	15474.840	21941.117	41.786	28.998	182.989
p4	300-300	17989.970	26163.125	45.432	29.247	182.366
p5	300-300	18037.610	26969.187	49.516	32.288	262.126
p6	300-300	11251.190	16361.485	45.420	28.836	155.764
p7	300-300	11392.520	15240.432	33.776	27.579	162.487
p8	300-300	11449.670	18053.145	57.674	29.382	145.980
p9	300-300	10932.880	15158.577	38.651	29.412	130.155
p10	300-300	11232.770	16987.877	51.235	29.106	120.574
p11	300-300	10046.940	15655.813	55.827	35.482	130.359
p12	300-300	9359.640	13377.224	42.925	28.919	126.872
p13	300-300	10103.490	15774.034	56.125	28.694	125.255
p14	300-300	9738.050	14160.212	45.411	27.939	122.664
p15	300-300	9902.260	14071.260	42.102	28.704	165.638
p16	300-300	9168.080	12551.815	36.908	28.796	114.611
p17	300-300	9181.070	13286.561	44.717	28.579	148.451
p18	300-300	9581.950	13326.034	39.074	28.373	137.220
p19	300-300	9062.160	12344.732	36.223	28.542	121.395

p20	300-300	9078.220	13438.616	48.031	29.599	116.901
p21	300-1500	154999.140	288986.689	86.444	131.818	20193.070
p22	300-1500	159438.600	308470.598	93.473	169.614	23911.429
p23	300-1500	157300.150	286819.808	82.339	171.781	19390.566
p24	300-1500	157796.280	322958.071	104.668	131.332	17193.486
p25	300-1500	161306.000	305487.246	89.384	137.390	15959.328
p26	300-1500	156669.280	361925.853	131.013	207.462	15274.546
p27	300-1500	157031.550	352600.394	124.541	150.237	17903.001
p28	300-1500	157802.830	364809.883	131.181	203.793	19776.681
p29	300-1500	156968.460	384229.179	144.781	154.253	20195.734
p30	300-1500	157764.390	363277.393	130.266	146.255	15994.110
p31	300-1500	150015.130	413257.492	175.477	194.011	17905.529
p32	300-1500	154937.670	411820.638	165.798	203.231	14569.812
p33	300-1500	151608.420	405457.692	167.437	146.733	18755.910
p34	300-1500	151848.050	401064.149	164.122	201.681	18449.983
p35	300-1500	156480.890	434898.268	177.924	135.550	16300.840
p36	300-1500	155495.620	482583.315	210.352	139.864	19912.805
p37	300-1500	156038.040	463274.138	196.898	136.418	16998.550
p38	300-1500	156799.930	403761.508	157.501	128.438	16766.690
p39	300-1500	155947.130	440128.727	182.229	135.857	17703.931
p40	300-1500	156426.140	458097.247	192.852	136.976	11927.802
p41	500-500	26412.410	39062.522	47.895	97.624	552.961
p42	500-500	28130.740	38916.127	38.340	105.816	891.610
p43	500-500	27904.510	39701.828	42.277	106.057	589.235
p44	500-500	28159.030	39658.661	40.838	113.649	592.570
p45	500-500	24702.770	35524.234	43.807	75.639	590.644
p46	500-500	15756.820	23697.210	50.393	105.223	557.734
p47	500-500	16109.280	24860.529	54.324	75.280	547.622
p48	500-500	16041.730	24344.863	51.760	70.440	646.335
p49	500-500	16327.710	25465.705	55.966	87.962	1192.287
p50	500-500	15815.130	23720.017	49.983	105.336	560.931
p51	500-500	13497.710	21445.403	58.882	73.723	605.625
p52	500-500	14675.020	22379.998	52.504	108.076	717.955
p53	500-500	13666.250	21182.438	54.998	105.862	885.682
p54	500-500	13629.540	19938.852	46.291	104.948	541.631
p55	500-500	13896.760	21874.580	57.408	71.871	556.452
p56	500-500	12618.680	19877.010	57.521	104.966	968.309
p57	500-500	13386.170	21142.427	57.942	73.815	511.574
p58	500-500	12852.520	19603.545	52.527	106.538	613.305
p59	500-500	13521.520	19756.288	46.110	80.019	449.242
p60	500-500	12362.260	19770.745	59.928	70.933	649.964
p61	700-700	36905.930	54900.551	48.758	130.627	2277.187
p62	700-700	34311.710	51826.116	51.045	129.495	1758.367
p63	700-700	34294.630	50161.409	46.266	130.285	1637.166
p64	700-700	38090.900	56885.615	49.342	159.661	2384.080
p65	700-700	37802.100	57743.091	52.751	189.476	1859.373

p66	700-700	19910.670	29868.529	50.013	136.926	2187.235
p67	700-700	21297.300	33500.808	57.301	131.529	1669.290
p68	700-700	20659.960	32435.200	56.995	136.601	1616.057
p69	700-700	20979.880	30907.063	47.318	156.720	1956.200
p70	700-700	22055.410	33462.779	51.721	140.625	1665.967
p71	700-700	17120.150	25333.984	47.978	156.434	1606.799
p72	700-700	18130.420	28881.184	59.297	200.153	1729.305
p73	700-700	17239.960	27780.931	61.143	141.479	1663.901
p74	700-700	17337.630	25738.575	48.455	180.933	1772.921
p75	700-700	18145.490	28251.439	55.694	169.282	1944.929
p76	700-700	16029.550	24980.764	55.842	163.692	1468.166
p77	700-700	16199.550	23531.307	45.259	150.055	1570.991
p78	700-700	16443.070	26109.668	58.788	145.900	2069.600
p79	700-700	16399.790	26626.389	62.358	133.717	1642.257
p80	700-700	15434.210	22112.831	43.272	134.169	2453.720
p81	1000-1000	49509.810	74892.283	51.268	257.731	5138.704
p82	1000-1000	50688.570	74386.582	46.752	390.864	7054.301
p83	1000-1000	47202.640	74797.075	58.460	262.100	7312.022
p84	1000-1000	48868.540	71034.543	45.358	259.400	4980.443
p85	1000-1000	50743.540	73896.830	45.628	310.439	5772.225
p86	1000-1000	27823.840	42933.095	54.303	255.769	4388.778
p87	1000-1000	27252.320	42648.641	56.495	256.372	4513.008
p88	1000-1000	27375.370	43255.598	58.009	258.767	4929.057
p89	1000-1000	26857.090	39143.251	45.746	261.351	4910.753
p90	1000-1000	27186.990	42118.582	54.922	259.074	4611.935
p91	1000-1000	22180.330	34917.641	57.426	275.329	7580.390
p92	1000-1000	22160.390	34480.925	55.597	273.734	5957.347
p93	1000-1000	22657.090	37063.855	63.586	267.073	4352.745
p94	1000-1000	22312.010	36334.589	62.848	295.857	5946.808
p95	1000-1000	22629.440	33743.927	49.115	416.743	7083.624
p96	1000-1000	21331.810	31609.532	48.180	451.193	4906.525
p97	1000-1000	21188.890	32741.947	54.524	280.789	4669.147
p98	1000-1000	20713.430	31679.208	52.940	270.993	4853.050
p99	1000-1000	20537.450	32239.376	56.978	432.238	8617.298
p100	1000-1000	21560.860	34733.959	61.097	538.464	10477.460

5 Conclusions

In this article, we addressed the Single Source Capacitated Facility Location Problem (SSCFLP).The SSCFLP Problem is focused on satisfying the clients demand with facilities, considering a set of possible locations for opening facilities. The objective is to minimize the cost of associating the clients with facilities, ensuring that all clients are served by only one facility without exceeding the capacity of the facilities.

To solve this problem, we used different approaches. Exact Method algorithm, constructive heuristic and metaheuristic methods were used.

For Exact Method algorithm we used OR-Tools, a library present in Python. OR-Tools allows solving the problem through a solver. However, due to the complexity of several instances and limitations at the software and hardware level, a time limit of 20 minutes was defined for this solver. With the definition of this time limit, despite being an exact solution, the algorithm was not able to reach the optimal solution in all cases, as there were quite numerous and complex instances, where time was not enough for this.

Since the exact methods are quite time-consuming, heuristic methods were used in order to reach a solution in a timely and easier way.

For the constructive heuristic method, we used a Local Search algorithm (swift and swap) as an inprovement, where the objective of this algorithm was to change the customer facility previously assigned to, in order to optimize the solution.

For the constructive metaheuristic method, we used a GRASP approach, also used a Local Search algorithm, but one with the swift approach and other with the swap approach.

When analyzing the data obtained with the execution of the developed algorithms, the main differences between them are their execution time and the difference in the solution found with the optimal solution. As can be noticed, the Exact Method is an algorithm that takes more time to be executed and even in certain problems, did not found a solution, due to exceeding the execution time we imposed in the Solver, but in the cases where a solution is found it is very close to optimal solution. For once, in the heuristic and metaheuristic constructive methods, the time to find a solution is much lower and the computational costs are also much shorter, but the solution found several times is not close to the optimal solution.

In general, the results were pleasant, only algorithms with different time limits could have been performed in Solver, in order to verify their influence. A transition to Cython could also have been made, that is, programming in Python but compiled in C, in order to increase the speed of the algorithms.

Another possible improvement would be to use an initial solution closer to the final solution, that is, one that comes from metaheuristic or heuristic methods with the exact method.

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