

# A biased random-key genetic algorithm for the home health care problem

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## Supplementary material

### New best lower bounds produced with CPLEX 20.10

Table A1: New best lower bounds found by CPLEX 12.10. The first column identifies the instance being solved, and the following two columns present the previous lower bound and the processing time reported by Mankowska et al. (2014). Column  $LB^+$  presents our new best lower bound, followed by the cost of the initial feasible solution used to warm-start the search and the solution value when the solver reached the time limit of two hours of processing. The following three columns present the relative gap to optimality of the final solution to the  $LB^+$ , the runtime of the solver, and the average improvement of  $LB^+$  compared to Mankowska et al.  $LB$ . Column “# nodes” highlights how many branch-and-cut nodes were explored. The last three columns present the problem size in terms of the number of rows/constraints, the number of columns/variables, and the number of non-zero elements on the matrix. Values in bold indicate the best lower bound available, and values marked with an asterisk indicate that an optimal solution was found.

| Instance | Previous results |             | New results    |              |            |         |             |           |           | Problem size |         |             |
|----------|------------------|-------------|----------------|--------------|------------|---------|-------------|-----------|-----------|--------------|---------|-------------|
|          | LB               | Time (sec.) | $LB^+$         | Initial sol. | Final sol. | Gap (%) | Time (sec.) | Impr. (%) | # nodes   | # rows       | # cols. | # non-zeros |
| A1       | <b>218.2</b>     | 2.9         | <b>218.2</b>   | *227.0       | 218.2      | 0.0     | 1.0         | 0.0       | 43        | 135          | 31      | 270         |
| A2       | <b>246.6</b>     | 7.4         | <b>246.6</b>   | *246.6       | 246.6      | 0.0     | 1.0         | 0.0       | 463       | 130          | 30      | 260         |
| A3       | <b>305.8</b>     | 10.3        | <b>305.9</b>   | *305.9       | 305.9      | 0.0     | 1.0         | 0.0       | 2,192     | 123          | 27      | 246         |
| A4       | <b>186.9</b>     | 11.8        | <b>186.9</b>   | *186.9       | 186.9      | 0.0     | 1.0         | 0.0       | 1,998     | 128          | 28      | 256         |
| A5       | <b>189.5</b>     | 2.9         | <b>189.5</b>   | *192.0       | 189.5      | 0.0     | 1.0         | 0.0       | 674       | 135          | 31      | 270         |
| A6       | <b>200.1</b>     | 2.9         | <b>200.1</b>   | *200.1       | 200.1      | 0.0     | 1.0         | 0.0       | 375       | 131          | 31      | 262         |
| A7       | <b>225.4</b>     | 1.5         | <b>225.4</b>   | *225.4       | 225.4      | 0.0     | 1.0         | 0.0       | 222       | 127          | 27      | 254         |
| A8       | <b>232.0</b>     | 5.9         | <b>232.0</b>   | *232.0       | 232.0      | 0.0     | 1.0         | 0.0       | 175       | 105          | 25      | 210         |
| A9       | <b>222.3</b>     | 29.4        | <b>222.3</b>   | *234.2       | 222.3      | 0.0     | 1.3         | 0.0       | 2,315     | 201          | 35      | 402         |
| A10      | <b>225.0</b>     | 1.5         | <b>225.0</b>   | *225.0       | 225.0      | 0.0     | 1.0         | 0.0       | 0         | 68           | 23      | 136         |
|          | <b>225.2</b>     | 7.7         | <b>225.2</b>   | 227.5        | 225.2      | 0.0     | 1.0         | 0.0       | 846       | 128          | 29      | 257         |
| B1       | 378.7            | 52987.5     | * <b>428.1</b> | 428.6        | *428.1     | 0.0     | 5970.3      | 13.0      | 3,149,921 | 1,249        | 98      | 2,498       |
| B2       | 427.9            | 52987.5     | * <b>476.0</b> | 483.6        | *476.0     | 0.0     | 469.5       | 11.2      | 268,511   | 841          | 88      | 1,682       |
| B3       | <b>391.2</b>     | 52987.5     | 371.4          | 402.8        | 399.1      | 6.9     | 7200.0      | -5.1      | 1,865,152 | 1,274        | 99      | 2,548       |
| B4       | 330.4            | 52987.5     | * <b>411.3</b> | 432.2        | *411.3     | 0.0     | 509.9       | 24.5      | 220,784   | 847          | 89      | 1,694       |
| B5       | 311.0            | 52987.5     | <b>363.7</b>   | 380.7        | 366.3      | 0.7     | 7200.0      | 16.9      | 2,044,932 | 1,091        | 90      | 2,182       |
| B6       | 274.2            | 52987.5     | <b>372.8</b>   | 472.8        | 467.3      | 20.2    | 7200.0      | 36.0      | 1,134,634 | 1,299        | 100     | 2,598       |
| B7       | 310.6            | 52987.5     | * <b>328.6</b> | *328.7       | *328.7     | 0.0     | 598.7       | 5.8       | 170,681   | 1,443        | 108     | 2,886       |
| B8       | 332.4            | 52987.5     | * <b>357.6</b> | 359.7        | *357.7     | 0.0     | 533.7       | 7.6       | 228,650   | 1,325        | 104     | 2,650       |
| B9       | 293.7            | 52987.5     | <b>336.9</b>   | 404.1        | 402.7      | 16.3    | 7200.0      | 14.7      | 748,709   | 1,763        | 116     | 3,526       |
| B10      | 381.0            | 52987.5     | <b>413.7</b>   | 469.6        | 469.6      | 11.9    | 7200.0      | 8.6       | 1,458,151 | 1,730        | 109     | 3,460       |
|          | 343.1            | 52,987.5    | <b>386.0</b>   | 416.3        | 410.7      | 5.6     | 4408.2      | 13.3      | 1,129,013 | 1,286        | 100     | 2,572       |

Table A1: Continued.

| Instance | Previous results |             | New results     |              |            |         |             |           |         | Problem size |         |             |
|----------|------------------|-------------|-----------------|--------------|------------|---------|-------------|-----------|---------|--------------|---------|-------------|
|          | LB               | Time (sec.) | LB <sup>+</sup> | Initial sol. | Final sol. | Gap (%) | Time (sec.) | Impr. (%) | # nodes | # rows       | # cols. | # non-zeros |
| C1       | 401.1            | 52987.5     | <b>477.3</b>    | 965.2        | 951.0      | 49.8    | 7200.0      | 19.0      | 24,016  | 10,059       | 327     | 20,118      |
| C2       | 314.9            | 52987.5     | <b>377.4</b>    | 584.3        | 577.9      | 34.7    | 7200.0      | 19.9      | 46,361  | 8,518        | 323     | 17,036      |
| C3       | 323.5            | 52987.5     | <b>396.4</b>    | 559.9        | 559.0      | 29.1    | 7200.0      | 22.5      | 44,907  | 8,318        | 320     | 16,636      |
| C4       | 329.4            | 52987.5     | <b>367.4</b>    | 537.2        | 513.3      | 28.4    | 7200.0      | 11.5      | 47,961  | 8,401        | 309     | 16,802      |
| C5       | 404.2            | 52987.5     | <b>496.9</b>    | 692.2        | 667.9      | 25.6    | 7200.0      | 22.9      | 43,036  | 6,527        | 277     | 13,054      |
| C6       | 308.2            | 52987.5     | <b>366.1</b>    | 843.7        | 838.9      | 56.4    | 7200.0      | 18.8      | 59,725  | 8,475        | 315     | 16,950      |
| C7       | 315.7            | 52987.5     | <b>365.2</b>    | 538.4        | 525.7      | 30.5    | 7200.0      | 15.7      | 26,149  | 11,895       | 374     | 23,790      |
| C8       | 336.3            | 52987.5     | <b>377.1</b>    | 481.0        | 473.1      | 20.3    | 7200.0      | 12.1      | 82,757  | 8,702        | 322     | 17,404      |
| C9       | 306.5            | 52987.5     | <b>361.5</b>    | 545.2        | 542.5      | 33.4    | 7200.0      | 18.0      | 44,903  | 10,627       | 361     | 21,254      |
| C10      | 386.4            | 52987.5     | <b>449.8</b>    | 619.4        | 601.5      | 25.2    | 7200.0      | 16.4      | 64,989  | 7,586        | 297     | 15,172      |
|          | 342.6            | 52,987.5    | <b>403.5</b>    | 636.6        | 625.1      | 33.3    | 7200.0      | 17.7      | 48,480  | 8,911        | 323     | 17,822      |
| D1       | 456.7            | 52987.5     | <b>514.4</b>    | 1199.5       | 1199.5     | 57.1    | 7200.0      | 12.6      | 6,223   | 31,400       | 684     | 62,800      |
| D2       | 336.8            | 52987.5     | <b>386.0</b>    | 706.8        | 693.9      | 44.4    | 7200.0      | 14.6      | 19,698  | 21,890       | 581     | 43,780      |
| D3       | 355.7            | 52987.5     | <b>379.5</b>    | 650.3        | 650.3      | 41.6    | 7200.0      | 6.7       | 1,386   | 33,255       | 718     | 66,510      |
| D4       | 379.9            | 52987.5     | <b>408.5</b>    | 822.8        | 822.8      | 50.4    | 7200.0      | 7.5       | 4,927   | 25,492       | 626     | 50,984      |
| D5       | 372.2            | 52987.5     | <b>404.3</b>    | 732.5        | 730.5      | 44.7    | 7200.0      | 8.6       | 4,644   | 28,839       | 661     | 57,678      |
| D6       | 368.8            | 52987.5     | <b>391.8</b>    | 735.4        | 735.4      | 46.7    | 7200.0      | 6.2       | 1,213   | 33,285       | 729     | 66,570      |
| D7       | 333.4            | 52987.5     | <b>359.0</b>    | 599.8        | 599.8      | 40.1    | 7200.0      | 7.7       | 4,746   | 37,734       | 762     | 75,468      |
| D8       | 373.3            | 52987.5     | <b>406.8</b>    | 661.8        | 661.8      | 38.5    | 7200.0      | 9.0       | 3,660   | 28,124       | 642     | 56,248      |
| D9       | 362.4            | 52987.5     | <b>387.6</b>    | 715.9        | 715.9      | 45.9    | 7200.0      | 7.0       | 2,570   | 26,518       | 662     | 53,036      |
| D10      | 434.4            | 52987.5     | <b>479.3</b>    | 1216.0       | 1203.0     | 60.2    | 7200.0      | 10.3      | 9,013   | 21,327       | 573     | 42,654      |
|          | 377.4            | 52,987.5    | <b>411.7</b>    | 804.1        | 801.3      | 47.0    | 7200.0      | 9.0       | 5,808   | 28,786       | 664     | 57,573      |
| E1       | 406.0            | 52987.5     | <b>421.8</b>    | 1375.3       | 1375.3     | 69.3    | 7200.0      | 3.9       | 797     | 61,719       | 1,059   | 123,438     |
| E2       | 411.9            | 52987.5     | <b>423.7</b>    | 905.0        | 905.0      | 53.2    | 7200.0      | 2.9       | 639     | 59,793       | 1,073   | 119,586     |
| E3       | 437.2            | 52987.5     | <b>445.2</b>    | 818.2        | 818.2      | 45.6    | 7200.0      | 1.8       | 601     | 62,443       | 1,101   | 124,886     |
| E4       | 384.3            | 52987.5     | <b>398.5</b>    | 732.7        | 732.7      | 45.6    | 7200.1      | 3.7       | 625     | 72,830       | 1,180   | 145,660     |
| E5       | 392.4            | 52987.5     | <b>403.6</b>    | 810.7        | 810.7      | 50.2    | 7200.0      | 2.9       | 587     | 67,981       | 1,141   | 135,962     |
| E6       | 390.2            | 52987.5     | <b>404.5</b>    | 814.0        | 814.0      | 50.3    | 7200.0      | 3.7       | 581     | 67,555       | 1,160   | 135,110     |
| E7       | 374.4            | 52987.5     | <b>384.7</b>    | 735.8        | 735.8      | 47.7    | 7200.1      | 2.8       | 911     | 77,000       | 1,240   | 154,000     |
| E8       | 407.7            | 52987.5     | <b>425.9</b>    | 761.8        | 761.8      | 44.1    | 7200.0      | 4.5       | 637     | 62,453       | 1,079   | 124,906     |
| E9       | 422.1            | 52987.5     | <b>431.2</b>    | 969.6        | 969.6      | 55.5    | 7200.0      | 2.2       | 610     | 57,914       | 1,082   | 115,828     |
| E10      | 419.1            | 52987.5     | <b>441.8</b>    | 867.2        | 867.2      | 49.1    | 7200.0      | 5.4       | 550     | 64,388       | 1,114   | 128,776     |
|          | 404.5            | 52,987.5    | <b>418.1</b>    | 879.0        | 879.0      | 51.1    | 7200.0      | 3.4       | 654     | 65,408       | 1,123   | 130,815     |
| F1       | 445.1            | 52987.5     | <b>546.7</b>    | 1504.1       | 1504.1     | 63.7    | 7200.7      | 22.8      | 519     | 412,064      | 3,316   | 824,128     |
| F2       | 457.9            | 52987.5     | <b>535.0</b>    | 1459.5       | 1459.5     | 63.3    | 7200.2      | 16.8      | 505     | 404,375      | 3,300   | 808,750     |
| F3       | 481.8            | 52987.5     | <b>541.6</b>    | 1327.9       | 1327.9     | 59.2    | 7200.2      | 12.4      | 479     | 415,629      | 3,375   | 831,258     |
| F4       | 417.4            | 52987.5     | <b>524.0</b>    | 1162.8       | 1162.8     | 54.9    | 7200.2      | 25.5      | 511     | 481,774      | 3,714   | 963,548     |
| F5       | 452.3            | 52987.5     | <b>529.0</b>    | 1391.9       | 1391.9     | 62.0    | 7200.2      | 17.0      | 487     | 480,978      | 3,602   | 961,956     |
| F6       | 367.1            | 52987.5     | <b>498.6</b>    | 1441.3       | 1441.3     | 65.4    | 7200.1      | 35.8      | 510     | 360,717      | 3,214   | 721,434     |
| F7       | 408.1            | 52987.5     | <b>502.5</b>    | 1177.9       | 1177.9     | 57.3    | 7200.3      | 23.1      | 520     | 426,764      | 3,301   | 853,528     |
| F8       | 454.3            | 52987.5     | <b>532.9</b>    | 1169.2       | 1169.2     | 54.4    | 7200.2      | 17.3      | 532     | 397,617      | 3,282   | 795,234     |
| F9       | 426.8            | 52987.5     | <b>535.9</b>    | 1346.7       | 1346.7     | 60.2    | 7200.1      | 25.6      | 504     | 434,158      | 3,526   | 868,316     |
| F10      | 441.8            | 52987.5     | <b>540.2</b>    | 1470.0       | 1470.0     | 63.3    | 7200.2      | 22.3      | 499     | 476,660      | 3,561   | 953,320     |
|          | 435.3            | 52,987.5    | <b>528.6</b>    | 1345.1       | 1345.1     | 60.4    | 7200.2      | 21.9      | 507     | 429,074      | 3,419   | 858,147     |
| G1       | 455.0            | 52987.5     | <b>584.6</b>    | 2037.0       | 2037.0     | 71.3    | 7200.2      | 28.5      | 352     | 1,309,443    | 6,620   | 2,618,886   |
| G2       | 463.1            | 52987.5     | <b>600.6</b>    | 2083.9       | 2083.9     | 71.2    | 7200.2      | 29.7      | 500     | 1,449,352    | 6,915   | 2,898,704   |

Table A1: Continued.

| Instance | Previous results |             | New results     |              |            |         |             |           |         | Problem size |         |             |  |
|----------|------------------|-------------|-----------------|--------------|------------|---------|-------------|-----------|---------|--------------|---------|-------------|--|
|          | LB               | Time (sec.) | LB <sup>+</sup> | Initial sol. | Final sol. | Gap (%) | Time (sec.) | Impr. (%) | # nodes | # rows       | # cols. | # non-zeros |  |
| G3       | 464.3            | 52987.5     | <b>584.8</b>    | 1608.2       | 1608.2     | 63.6    | 7200.2      | 25.9      | 257     | 1,227,143    | 6,485   | 2,454,286   |  |
| G4       | 461.5            | 52987.5     | <b>591.9</b>    | 1723.0       | 1723.0     | 65.6    | 7200.7      | 28.2      | 461     | 1,435,781    | 7,043   | 2,871,562   |  |
| G5       | 449.4            | 52987.5     | <b>616.5</b>    | 1809.8       | 1809.8     | 65.9    | 7200.6      | 37.2      | 32      | 1,280,623    | 6,443   | 2,561,246   |  |
| G6       | 471.5            | 52987.5     | <b>583.5</b>    | 1949.1       | 1949.1     | 70.1    | 7201.9      | 23.8      | 304     | 1,482,588    | 7,147   | 2,965,176   |  |
| G7       | 459.1            | 52987.5     | <b>604.8</b>    | 1777.5       | 1777.5     | 66.0    | 7200.2      | 31.7      | 496     | 1,270,343    | 6,642   | 2,540,686   |  |
| G8       | 472.4            | 52987.5     | <b>618.3</b>    | 1754.2       | 1754.2     | 64.8    | 7200.6      | 30.9      | 483     | 1,223,060    | 6,531   | 2,446,120   |  |
| G9       | 473.3            | 52987.5     | <b>637.4</b>    | 2120.5       | 2120.5     | 69.9    | 7200.6      | 34.7      | 100     | 1,230,118    | 6,515   | 2,460,236   |  |
| G10      | 451.6            | 52987.5     | <b>621.0</b>    | 2022.3       | 2022.3     | 69.3    | 7200.5      | 37.5      | 38      | 1,186,772    | 6,232   | 2,373,544   |  |
|          | 462.1            | 52,987.5    | <b>604.3</b>    | 1888.5       | 1888.5     | 67.8    | 7200.6      | 30.8      | 302     | 1,309,522    | 6,657   | 2,619,045   |  |

## Detailed results regarding BRKGA-MP-IPR convergence

Table B2: Solution improvement during the search with the BRKGA-MP-IPR based metaheuristic. The first column presents the instance name, and each one of the next pair of columns presents the average runtime in seconds, and the average solution cost after completing 5%, 25%, 50%, 75%, and 100% of the evolutionary process. The values present the average of 15 runs of the metaheuristic on each instance.

| Instance | 95 gens (5%) |              | 475 gens (25%) |              | 950 gens (50%) |              | 1425 gens (75%) |              | 1900 gens (100%) |               |
|----------|--------------|--------------|----------------|--------------|----------------|--------------|-----------------|--------------|------------------|---------------|
|          | Time (sec)   | Cost (avg)   | Time (sec)     | Cost (avg)   | Time (sec)     | Cost (avg)   | Time (sec)      | Cost (avg)   | Time (sec)       | Cost (avg)    |
| A1       | 5.0          | <b>227.0</b> | 24.7           | <b>227.0</b> | 49.4           | <b>227.0</b> | 74.0            | <b>227.0</b> | 98.6             | <b>227.0</b>  |
| A2       | 4.9          | <b>246.6</b> | 24.4           | <b>246.6</b> | 48.7           | <b>246.6</b> | 73.1            | <b>246.6</b> | 97.3             | <b>246.6</b>  |
| A3       | 5.0          | <b>305.9</b> | 25.0           | <b>305.9</b> | 49.9           | <b>305.9</b> | 74.8            | <b>305.9</b> | 99.6             | <b>305.9</b>  |
| A4       | 4.9          | <b>186.9</b> | 24.4           | <b>186.9</b> | 48.9           | <b>186.9</b> | 73.2            | <b>186.9</b> | 97.6             | <b>186.9</b>  |
| A5       | 4.9          | <b>192.0</b> | 24.4           | <b>192.0</b> | 48.8           | <b>192.0</b> | 73.1            | <b>192.0</b> | 97.4             | <b>192.0</b>  |
| A6       | 5.0          | <b>200.2</b> | 24.6           | <b>200.2</b> | 49.1           | <b>200.1</b> | 73.6            | <b>200.1</b> | 98.1             | <b>200.1</b>  |
| A7       | 4.9          | <b>225.4</b> | 24.4           | <b>225.4</b> | 48.7           | <b>225.4</b> | 72.9            | <b>225.4</b> | 97.2             | <b>225.4</b>  |
| A8       | 5.0          | <b>232.1</b> | 24.7           | <b>232.1</b> | 49.3           | <b>232.1</b> | 73.9            | <b>232.1</b> | 98.4             | <b>232.1</b>  |
| A9       | 4.9          | <b>234.2</b> | 24.2           | <b>234.2</b> | 48.3           | <b>234.2</b> | 72.5            | <b>234.2</b> | 96.5             | <b>234.2</b>  |
| A10      | 4.9          | <b>225.0</b> | 24.1           | <b>225.0</b> | 48.2           | <b>225.0</b> | 72.2            | <b>225.0</b> | 96.2             | <b>225.0</b>  |
|          | 4.9          | <b>227.5</b> | 24.5           | <b>227.5</b> | 48.9           | <b>227.5</b> | 73.3            | <b>227.5</b> | 97.7             | <b>227.5</b>  |
| B1       | 5.3          | 428.5        | 26.0           | 428.2        | 52.0           | <b>428.1</b> | 78.0            | <b>428.1</b> | 103.9            | <b>428.1</b>  |
| B2       | 5.3          | 484.0        | 26.4           | 484.0        | 52.8           | 483.8        | 79.2            | <b>483.6</b> | 105.5            | <b>483.6</b>  |
| B3       | 5.3          | 403.2        | 26.2           | <b>402.8</b> | 52.2           | <b>402.8</b> | 78.3            | <b>402.8</b> | 104.4            | <b>402.8</b>  |
| B4       | 5.4          | 432.5        | 26.6           | 431.6        | 53.0           | 429.9        | 79.5            | 429.9        | 105.9            | <b>429.1</b>  |
| B5       | 5.2          | 374.3        | 25.6           | 374.3        | 51.1           | 373.1        | 76.7            | 373.1        | 102.2            | <b>373.0</b>  |
| B6       | 5.4          | 471.9        | 27.0           | 471.2        | 53.9           | <b>471.0</b> | 80.9            | <b>471.0</b> | 107.8            | <b>471.0</b>  |
| B7       | 5.3          | <b>328.7</b> | 26.2           | <b>328.7</b> | 52.3           | <b>328.7</b> | 78.4            | <b>328.7</b> | 104.5            | <b>328.7</b>  |
| B8       | 5.4          | <b>359.7</b> | 26.6           | <b>359.7</b> | 53.1           | <b>359.7</b> | 79.6            | <b>359.7</b> | 106.0            | <b>359.7</b>  |
| B9       | 5.4          | 403.8        | 26.9           | 403.8        | 53.7           | 403.4        | 80.5            | 403.4        | 107.3            | <b>403.2</b>  |
| B10      | 5.4          | <b>469.6</b> | 26.8           | <b>469.6</b> | 53.5           | <b>469.6</b> | 80.2            | <b>469.6</b> | 106.8            | <b>469.6</b>  |
|          | 5.3          | 415.6        | 26.4           | 415.4        | 52.8           | 415.0        | 79.1            | 415.0        | 105.4            | <b>414.9</b>  |
| C1       | 6.4          | 971.2        | 31.9           | 968.3        | 63.7           | 968.2        | 95.5            | 966.9        | 127.2            | <b>966.6</b>  |
| C2       | 6.9          | 586.3        | 33.9           | 583.5        | 67.8           | 583.1        | 101.6           | <b>582.9</b> | 135.4            | <b>582.9</b>  |
| C3       | 6.6          | 555.4        | 32.6           | 551.8        | 65.2           | 551.7        | 97.7            | 551.6        | 130.2            | <b>551.4</b>  |
| C4       | 6.5          | 528.8        | 32.0           | 525.6        | 63.9           | 523.9        | 95.8            | 523.5        | 127.6            | <b>523.2</b>  |
| C5       | 6.6          | 689.4        | 32.6           | 680.6        | 65.1           | 678.0        | 97.7            | 675.9        | 130.1            | <b>675.3</b>  |
| C6       | 6.5          | 846.3        | 32.1           | 843.9        | 64.2           | 843.0        | 96.2            | 842.6        | 128.2            | <b>842.4</b>  |
| C7       | 6.8          | 537.9        | 33.5           | 536.2        | 66.9           | 534.5        | 100.2           | 533.2        | 133.5            | <b>532.5</b>  |
| C8       | 6.8          | 479.0        | 33.5           | 476.7        | 66.8           | 475.8        | 100.2           | 475.2        | 133.5            | <b>475.1</b>  |
| C9       | 6.6          | 547.9        | 32.8           | 543.4        | 65.5           | 542.3        | 98.1            | 539.3        | 130.7            | <b>538.7</b>  |
| C10      | 6.6          | 615.4        | 32.6           | 613.9        | 65.2           | 613.4        | 97.7            | 613.3        | 130.2            | <b>612.3</b>  |
|          | 6.6          | 635.7        | 32.8           | 632.4        | 65.4           | 631.4        | 98.1            | 630.4        | 130.7            | <b>630.0</b>  |
| D1       | 8.6          | 1219.7       | 42.4           | 1199.6       | 84.7           | 1198.0       | 127.0           | 1197.4       | 169.3            | <b>1195.9</b> |
| D2       | 7.9          | 744.2        | 39.0           | 705.0        | 77.9           | 704.2        | 116.8           | 695.2        | 155.5            | <b>694.8</b>  |
| D3       | 8.6          | 660.4        | 42.6           | 644.5        | 85.2           | 643.7        | 127.7           | 641.0        | 170.2            | <b>640.6</b>  |
| D4       | 8.1          | 855.8        | 40.1           | 838.4        | 80.0           | 837.0        | 120.0           | 830.7        | 159.8            | <b>829.6</b>  |
| D5       | 8.4          | 723.5        | 41.5           | 698.4        | 82.8           | 696.7        | 124.2           | 693.8        | 165.5            | <b>691.8</b>  |
| D6       | 8.6          | 755.8        | 42.8           | 734.3        | 85.4           | 733.4        | 128.1           | 729.9        | 170.7            | <b>727.6</b>  |
| D7       | 9.0          | 617.7        | 44.5           | 600.1        | 89.0           | 598.1        | 133.4           | 597.0        | 177.8            | <b>592.4</b>  |
| D8       | 8.7          | 688.7        | 42.9           | 670.0        | 85.7           | 668.3        | 128.5           | 664.1        | 171.2            | <b>663.3</b>  |
| D9       | 8.2          | 762.2        | 40.7           | 719.6        | 81.2           | 718.1        | 121.9           | 715.7        | 162.4            | <b>713.7</b>  |

(Continues on next page.)

| Instance | 95 gens (5%) |            | 475 gens (25%) |            | 950 gens (50%) |            | 1425 gens (75%) |            | 1900 gens (100%) |               |
|----------|--------------|------------|----------------|------------|----------------|------------|-----------------|------------|------------------|---------------|
|          | Time (sec)   | Cost (avg) | Time (sec)     | Cost (avg) | Time (sec)     | Cost (avg) | Time (sec)      | Cost (avg) | Time (sec)       | Cost (avg)    |
| D10      | 7.9          | 1273.9     | 39.3           | 1235.3     | 78.5           | 1228.0     | 117.7           | 1226.0     | 156.8            | <b>1223.5</b> |
|          | 8.4          | 830.2      | 41.6           | 804.5      | 83.0           | 802.6      | 124.5           | 799.1      | 165.9            | <b>797.3</b>  |
| E1       | 11.1         | 1435.2     | 54.9           | 1348.1     | 109.5          | 1338.5     | 164.3           | 1336.6     | 219.0            | <b>1335.1</b> |
| E2       | 11.1         | 1000.1     | 54.7           | 861.7      | 109.1          | 855.6      | 163.6           | 849.1      | 218.1            | <b>846.1</b>  |
| E3       | 10.9         | 873.1      | 54.3           | 804.3      | 108.5          | 802.3      | 162.8           | 798.4      | 216.9            | <b>794.4</b>  |
| E4       | 11.2         | 796.6      | 55.5           | 726.8      | 111.1          | 724.3      | 166.7           | 721.6      | 222.2            | <b>720.3</b>  |
| E5       | 11.0         | 898.3      | 54.4           | 787.5      | 108.7          | 785.8      | 163.0           | 782.6      | 217.2            | <b>777.2</b>  |
| E6       | 11.3         | 895.6      | 55.9           | 791.5      | 111.6          | 790.7      | 167.4           | 790.1      | 223.3            | <b>788.4</b>  |
| E7       | 11.7         | 787.8      | 57.9           | 725.4      | 115.6          | 724.0      | 173.4           | 721.6      | 231.2            | <b>720.7</b>  |
| E8       | 11.0         | 831.5      | 54.3           | 750.0      | 108.5          | 746.6      | 162.8           | 745.2      | 217.1            | <b>743.6</b>  |
| E9       | 10.9         | 1077.5     | 53.7           | 932.7      | 106.8          | 926.8      | 160.0           | 916.6      | 213.4            | <b>913.8</b>  |
| E10      | 11.1         | 939.2      | 55.1           | 843.3      | 109.9          | 835.8      | 164.8           | 831.7      | 219.6            | <b>828.2</b>  |
|          | 11.1         | 953.5      | 55.1           | 857.1      | 109.9          | 853.0      | 164.9           | 849.3      | 219.8            | <b>846.8</b>  |
| F1       | 27.0         | 1861.6     | 134.5          | 1388.4     | 268.2          | 1376.9     | 402.0           | 1374.4     | 535.8            | <b>1373.7</b> |
| F2       | 28.8         | 1826.5     | 141.6          | 1352.8     | 282.4          | 1328.4     | 423.2           | 1323.5     | 564.1            | <b>1322.8</b> |
| F3       | 27.7         | 1643.5     | 137.8          | 1243.1     | 274.9          | 1229.3     | 411.8           | 1228.8     | 549.0            | <b>1228.5</b> |
| F4       | 32.3         | 1462.0     | 160.7          | 1117.7     | 320.8          | 1110.6     | 480.7           | 1108.8     | 640.9            | <b>1107.6</b> |
| F5       | 29.9         | 1734.5     | 148.5          | 1326.8     | 296.3          | 1319.9     | 444.2           | 1318.0     | 592.3            | <b>1317.0</b> |
| F6       | 26.4         | 1766.9     | 131.3          | 1347.8     | 261.7          | 1321.9     | 392.0           | 1317.5     | 522.5            | <b>1315.5</b> |
| F7       | 31.9         | 1484.1     | 157.0          | 1129.2     | 312.8          | 1123.0     | 468.7           | 1121.1     | 624.7            | <b>1119.1</b> |
| F8       | 28.9         | 1501.1     | 142.4          | 1138.2     | 283.5          | 1133.9     | 424.8           | 1133.1     | 566.3            | <b>1131.1</b> |
| F9       | 30.1         | 1729.4     | 149.5          | 1307.7     | 297.6          | 1294.8     | 445.7           | 1293.3     | 594.0            | <b>1291.4</b> |
| F10      | 29.2         | 1848.0     | 145.8          | 1407.7     | 291.3          | 1397.5     | 436.8           | 1393.7     | 582.4            | <b>1392.6</b> |
|          | 29.2         | 1685.8     | 144.9          | 1275.9     | 288.9          | 1263.6     | 433.0           | 1261.2     | 577.2            | <b>1259.9</b> |
| G1       | 61.3         | 2511.3     | 302.5          | 1859.1     | 601.5          | 1755.9     | 900.3           | 1750.7     | 1198.9           | <b>1749.3</b> |
| G2       | 66.5         | 2636.0     | 327.0          | 1934.8     | 650.8          | 1786.3     | 974.3           | 1775.9     | 1297.8           | <b>1771.0</b> |
| G3       | 60.6         | 2094.1     | 298.6          | 1546.0     | 593.3          | 1480.9     | 887.1           | 1475.2     | 1180.6           | <b>1474.4</b> |
| G4       | 68.9         | 2172.3     | 339.7          | 1587.0     | 675.6          | 1528.2     | 1010.3          | 1524.4     | 1345.7           | <b>1523.1</b> |
| G5       | 58.9         | 2398.6     | 288.3          | 1740.9     | 571.8          | 1656.8     | 854.7           | 1652.0     | 1137.4           | <b>1650.9</b> |
| G6       | 71.6         | 2441.6     | 355.4          | 1808.1     | 707.5          | 1691.3     | 1057.8          | 1685.4     | 1408.2           | <b>1682.8</b> |
| G7       | 62.4         | 2288.9     | 306.6          | 1700.0     | 608.6          | 1597.2     | 909.5           | 1592.8     | 1210.5           | <b>1590.6</b> |
| G8       | 61.1         | 2142.5     | 299.9          | 1655.4     | 595.6          | 1514.9     | 890.3           | 1505.1     | 1185.1           | <b>1503.0</b> |
| G9       | 62.1         | 2663.5     | 305.9          | 2182.8     | 608.6          | 1977.0     | 909.8           | 1890.3     | 1210.9           | <b>1880.3</b> |
| G10      | 57.0         | 2704.5     | 281.0          | 2062.5     | 558.4          | 1838.3     | 834.3           | 1827.4     | 1110.0           | <b>1822.4</b> |
|          | 63.0         | 2405.3     | 310.5          | 1807.6     | 617.2          | 1682.7     | 922.8           | 1667.9     | 1228.5           | <b>1664.8</b> |

## Comparison of local-search based methods of the literature

Table C3: Gap values are relative to the best solution produced by each solution method with respect to the value of  $LB^+$ . Values in bold indicate the best-known solution value produced by the methods, and values marked with an asterisk indicate that an optimal solution was found. Mankowska et al. (2014) and Kummer et al. (2019) methods do not employ multiple runs of their algorithms. Lasfargeas et al. (2019) run a VNS based metaheuristic 40 times on each instance, and we run our BRKGA-MP-IPR only 15 times. Both methods use different random seeds on each one of the runs on each instance. All reported running times are in seconds.

| Instance | $LB^+$ | Mankowska et al. (2014) |      |         |         | Lasfargeas et al. (2019) |      |        |       |       | Kummer et al. (2019) |      |        | BRKGA-MP-IPR  |      |       |     |       |
|----------|--------|-------------------------|------|---------|---------|--------------------------|------|--------|-------|-------|----------------------|------|--------|---------------|------|-------|-----|-------|
|          |        | Best                    | Gap  | Method  | Time    | Best                     | Gap  | Mean   | SD    | Time  | Best                 | Gap  | Time   | Best          | Gap  | Mean  | SD  | Time  |
| A1       | *218.2 | <b>*218.2</b>           | 0.0  | CPLEX   | 2.9     | <b>*218.2</b>            | 0.0  | 224.3  | 14.6  | 1.0   | <b>*218.2</b>        | 0.0  | 0.2    | 227.0         | 3.9  | 227.0 | 0.0 | 98.6  |
| A2       | *246.6 | <b>*246.6</b>           | 0.0  | CPLEX   | 7.4     | <b>*246.6</b>            | 0.0  | 258.1  | 31.6  | 1.0   | <b>*246.6</b>        | 0.0  | 0.3    | <b>*246.6</b> | 0.0  | 246.6 | 0.0 | 97.3  |
| A3       | *305.9 | <b>*305.9</b>           | 0.0  | CPLEX   | 10.3    | <b>*305.9</b>            | 0.0  | 358.8  | 38.5  | 1.0   | <b>*305.9</b>        | 0.0  | 0.6    | <b>*305.9</b> | 0.0  | 305.9 | 0.0 | 99.6  |
| A4       | *186.9 | <b>*186.9</b>           | 0.0  | CPLEX   | 11.8    | <b>*186.9</b>            | 0.0  | 196.4  | 11.1  | 1.0   | <b>*186.9</b>        | 0.0  | 2.1    | <b>*186.9</b> | 0.0  | 186.9 | 0.0 | 97.6  |
| A5       | *189.5 | <b>*189.5</b>           | 0.0  | CPLEX   | 2.9     | <b>*189.5</b>            | 0.0  | 216.5  | 36.6  | 1.0   | <b>*189.5</b>        | 0.0  | 0.3    | 192.0         | 1.3  | 192.0 | 0.0 | 97.4  |
| A6       | *200.1 | <b>*200.1</b>           | 0.0  | CPLEX   | 2.9     | <b>*200.1</b>            | 0.0  | 200.1  | 0.0   | 1.0   | <b>*200.1</b>        | 0.0  | 0.2    | <b>*200.1</b> | 0.0  | 200.1 | 0.0 | 98.1  |
| A7       | *225.4 | <b>*225.4</b>           | 0.0  | CPLEX   | 1.5     | <b>*225.4</b>            | 0.0  | 232.4  | 24.2  | 1.0   | <b>*225.4</b>        | 0.0  | 0.2    | <b>*225.4</b> | 0.0  | 225.4 | 0.0 | 97.2  |
| A8       | *232.0 | <b>*232.0</b>           | 0.0  | CPLEX   | 5.9     | <b>*232.0</b>            | 0.0  | 281.4  | 47.6  | 1.0   | <b>*232.0</b>        | 0.0  | 0.2    | <b>*232.0</b> | 0.0  | 232.1 | 0.0 | 98.4  |
| A9       | *222.3 | <b>*222.3</b>           | 0.0  | CPLEX   | 29.4    | <b>*222.3</b>            | 0.0  | 225.4  | 4.0   | 1.0   | <b>*222.3</b>        | 0.0  | 1.5    | 234.2         | 5.1  | 234.2 | 0.0 | 96.5  |
| A10      | *225.0 | <b>*225.0</b>           | 0.0  | CPLEX   | 1.5     | <b>*225.0</b>            | 0.0  | 225.0  | 0.0   | 1.0   | <b>*225.0</b>        | 0.0  | 0.1    | <b>*225.0</b> | 0.0  | 225.0 | 0.0 | 96.2  |
|          | 225.2  | <b>225.2</b>            | 0.0  |         | 7.7     | <b>225.2</b>             | 0.0  | 241.8  | 20.8  | 1.0   | <b>225.2</b>         | 0.0  | 0.5    | 227.5         | 1.0  | 227.5 | 0.0 | 97.7  |
| B1       | *428.1 | 458.9                   | 6.7  | AVNS-TL | 1.0     | 434.1                    | 1.4  | 552.8  | 93.4  | 104.9 | 431.1                | 0.7  | 67.3   | <b>*428.1</b> | 0.0  | 428.1 | 0.0 | 103.9 |
| B2       | *476.0 | 476.2                   | 0.0  | CPLEX   | 52987.5 | <b>*476.0</b>            | 0.0  | 561.3  | 61.4  | 54.7  | <b>*476.0</b>        | 0.0  | 10.6   | 483.6         | 1.6  | 483.6 | 0.0 | 105.5 |
| B3       | 371.4  | 399.2                   | 7.0  | CPLEX   | 52987.5 | <b>399.1</b>             | 6.9  | 527.6  | 72.5  | 125.4 | 421.9                | 12.0 | 180.7  | 402.8         | 7.8  | 402.8 | 0.0 | 104.4 |
| B4       | *411.3 | 576.0                   | 28.6 | CPLEX   | 52987.5 | <b>414.0</b>             | 0.7  | 509.7  | 74.5  | 131.9 | 432.3                | 4.9  | 20.2   | 420.3         | 2.1  | 429.1 | 5.3 | 105.9 |
| B5       | 363.7  | 391.1                   | 7.0  | AVNS-TL | 1.0     | 385.6                    | 5.7  | 496.9  | 98.1  | 27.1  | <b>369.4</b>         | 1.6  | 100.8  | 372.2         | 2.3  | 373.0 | 2.2 | 102.2 |
| B6       | 372.8  | 534.7                   | 30.3 | MN      | 1.0     | <b>447.8</b>             | 16.7 | 611.8  | 129.9 | 86.3  | 531.9                | 29.9 | 111.9  | 471.0         | 20.8 | 471.0 | 0.0 | 107.8 |
| B7       | *328.6 | 355.5                   | 7.6  | MN      | 1.0     | <b>*328.7</b>            | 0.0  | 398.8  | 64.8  | 121.5 | <b>*328.7</b>        | 0.0  | 20.8   | <b>*328.7</b> | 0.0  | 328.7 | 0.0 | 104.5 |
| B8       | *357.6 | 357.8                   | 0.0  | CPLEX   | 52987.5 | 359.7                    | 0.6  | 488.7  | 116.2 | 156.6 | <b>*357.7</b>        | 0.0  | 78.1   | 359.7         | 0.6  | 359.7 | 0.0 | 106.0 |
| B9       | 336.9  | 403.8                   | 16.6 | CPLEX   | 52987.5 | 404.1                    | 16.6 | 483.4  | 60.3  | 122.6 | 446.6                | 24.6 | 261.1  | <b>402.7</b>  | 16.3 | 403.2 | 0.7 | 107.3 |
| B10      | 413.7  | 500.4                   | 17.3 | MN      | 1.0     | <b>462.7</b>             | 10.6 | 616.8  | 147.7 | 17.2  | 469.6                | 11.9 | 170.5  | 469.6         | 11.9 | 469.6 | 0.0 | 106.8 |
|          | 386.0  | 445.4                   | 13.3 |         | 26494.3 | <b>411.2</b>             | 6.1  | 524.8  | 91.9  | 94.8  | 426.5                | 9.5  | 102.2  | 413.9         | 6.7  | 414.9 | 0.8 | 105.4 |
| C1       | 477.3  | 1123.6                  | 57.5 | AVNS-TL | 1.0     | 974.2                    | 51.0 | 1350.4 | 365.3 | 190.0 | 1006.7               | 52.6 | 1141.6 | <b>965.2</b>  | 50.5 | 966.6 | 1.9 | 127.2 |
| C2       | 377.4  | 673.8                   | 44.0 | MN      | 1.0     | 605.1                    | 37.6 | 685.5  | 55.6  | 210.1 | 597.1                | 36.8 | 215.5  | <b>582.2</b>  | 35.2 | 582.9 | 1.2 | 135.4 |
| C3       | 396.4  | 642.4                   | 38.3 | AVNS-TL | 1.0     | 562.9                    | 29.6 | 698.2  | 82.7  | 216.9 | 618.3                | 35.9 | 346.0  | <b>548.8</b>  | 27.8 | 551.4 | 1.5 | 130.2 |
| C4       | 367.4  | 580.4                   | 36.7 | AVNS-TL | 1.0     | 521.9                    | 29.6 | 630.4  | 101.8 | 222.0 | 544.6                | 32.5 | 94.0   | <b>519.8</b>  | 29.3 | 523.2 | 2.5 | 127.6 |
| C5       | 496.9  | 754.6                   | 34.2 | AVNS-TL | 1.0     | 683.1                    | 27.3 | 822.6  | 119.3 | 226.9 | <b>667.5</b>         | 25.6 | 184.0  | 670.6         | 25.9 | 675.3 | 4.4 | 130.1 |
| C6       | 366.1  | 951.6                   | 61.5 | AVNS-TL | 1.0     | 854.6                    | 57.2 | 1010.6 | 146.4 | 228.9 | 852.0                | 57.0 | 915.9  | <b>840.7</b>  | 56.4 | 842.4 | 1.4 | 128.2 |
| C7       | 365.2  | 577.4                   | 36.7 | AVNS-TL | 1.0     | 529.2                    | 31.0 | 572.5  | 29.7  | 216.1 | <b>525.2</b>         | 30.5 | 488.9  | 528.5         | 30.9 | 532.5 | 3.4 | 133.5 |
| C8       | 377.1  | 540.6                   | 30.3 | AVNS-TL | 1.0     | <b>471.0</b>             | 19.9 | 522.8  | 29.8  | 218.8 | 479.4                | 21.4 | 457.3  | 472.0         | 20.1 | 475.1 | 1.5 | 133.5 |
| C9       | 361.5  | 608.7                   | 40.6 | AVNS-TL | 1.0     | 551.1                    | 34.4 | 642.7  | 77.6  | 227.9 | 568.9                | 36.4 | 539.8  | <b>531.2</b>  | 31.9 | 538.7 | 4.5 | 130.7 |

Table C3: Continued.

| Instance | LB <sup>+</sup> | Mankowska et al. (2014) |      |         |         | Lasfargeas et al. (2019) |      |        |       |       | Kummer et al. (2019) |      |        | BRKGA-MP-IPR  |      |        |      |        |
|----------|-----------------|-------------------------|------|---------|---------|--------------------------|------|--------|-------|-------|----------------------|------|--------|---------------|------|--------|------|--------|
|          |                 | Best                    | Gap  | Method  | Time    | Best                     | Gap  | Mean   | SD    | Time  | Best                 | Gap  | Time   | Best          | Gap  | Mean   | SD   | Time   |
| C10      | 449.8           | 679.3                   | 33.8 | AVNS-TL | 1.0     | 608.9                    | 26.1 | 653.0  | 35.6  | 195.5 | <b>603.5</b>         | 25.5 | 372.8  | 610.9         | 26.4 | 612.3  | 2.0  | 130.2  |
|          | 403.5           | 713.2                   | 43.4 |         | 1.0     | 636.2                    | 36.6 | 758.9  | 104.4 | 215.3 | 646.3                | 37.6 | 475.6  | <b>627.0</b>  | 35.6 | 630.0  | 2.4  | 130.7  |
| D1       | 514.4           | 1321.8                  | 61.1 | AVNS-TL | 7.4     | 1278.2                   | 59.8 | 1498.8 | 199.0 | 282.4 | 1301.0               | 60.5 | 1912.2 | <b>1179.9</b> | 56.4 | 1195.9 | 7.1  | 169.3  |
| D2       | 386.0           | 892.7                   | 56.8 | AVNS-TL | 5.9     | 746.9                    | 48.3 | 914.3  | 97.9  | 333.2 | 807.3                | 52.2 | 886.7  | <b>684.3</b>  | 43.6 | 694.8  | 7.3  | 155.5  |
| D3       | 379.5           | 819.4                   | 53.7 | AVNS-TL | 5.9     | 678.6                    | 44.1 | 817.8  | 80.9  | 306.9 | 675.3                | 43.8 | 1812.7 | <b>633.4</b>  | 40.1 | 640.6  | 4.0  | 170.2  |
| D4       | 408.5           | 877.4                   | 53.4 | AVNS-TL | 5.9     | 809.7                    | 49.6 | 1073.1 | 197.5 | 293.3 | 817.8                | 50.1 | 1543.2 | <b>804.4</b>  | 49.2 | 829.6  | 14.2 | 159.8  |
| D5       | 404.3           | 872.1                   | 53.6 | AVNS-TL | 7.4     | 777.0                    | 48.0 | 924.9  | 120.8 | 296.8 | 706.8                | 42.8 | 954.5  | <b>682.8</b>  | 40.8 | 691.8  | 4.6  | 165.5  |
| D6       | 391.8           | 835.2                   | 53.1 | AVNS-TL | 7.4     | 768.6                    | 49.0 | 886.6  | 97.4  | 305.3 | 762.3                | 48.6 | 1227.0 | <b>712.1</b>  | 45.0 | 727.6  | 6.5  | 170.7  |
| D7       | 359.0           | 706.3                   | 49.2 | AVNS-TL | 8.8     | 600.1                    | 40.2 | 680.4  | 31.6  | 332.0 | 671.7                | 46.5 | 835.6  | <b>585.6</b>  | 38.7 | 592.4  | 5.0  | 177.8  |
| D8       | 406.8           | 811.4                   | 49.9 | AVNS-TL | 5.9     | 715.5                    | 43.1 | 775.8  | 31.1  | 295.9 | 717.3                | 43.3 | 869.7  | <b>658.4</b>  | 38.2 | 663.3  | 3.0  | 171.2  |
| D9       | 387.6           | 842.7                   | 54.0 | MN      | 8.8     | 741.0                    | 47.7 | 818.2  | 46.5  | 308.1 | 739.6                | 47.6 | 265.0  | <b>696.2</b>  | 44.3 | 713.7  | 12.1 | 162.4  |
| D10      | 479.3           | 1306.6                  | 63.3 | AVNS-TL | 4.4     | 1424.6                   | 66.4 | 1867.7 | 258.6 | 341.9 | 1330.4               | 64.0 | 826.1  | <b>1201.7</b> | 60.1 | 1223.5 | 21.1 | 156.8  |
|          | 411.7           | 928.6                   | 55.7 |         | 6.8     | 854.0                    | 51.8 | 1025.8 | 116.1 | 309.6 | 853.0                | 51.7 | 1113.3 | <b>783.9</b>  | 47.5 | 797.3  | 8.5  | 165.9  |
| E1       | 421.8           | 1604.9                  | 73.7 | AVNS-TL | 25.0    | –                        | –    | –      | –     | –     | 1349.2               | 68.7 | 5639.2 | <b>1318.9</b> | 68.0 | 1335.1 | 10.6 | 219.0  |
| E2       | 423.7           | 1101.9                  | 61.6 | LS      | 14.7    | –                        | –    | –      | –     | –     | 941.3                | 55.0 | 4236.6 | <b>824.2</b>  | 48.6 | 846.1  | 16.6 | 218.1  |
| E3       | 445.2           | 986.4                   | 54.9 | AVNS-TL | 20.6    | –                        | –    | –      | –     | –     | 913.5                | 51.3 | 2905.4 | <b>785.1</b>  | 43.3 | 794.4  | 7.4  | 216.9  |
| E4       | 398.5           | 871.0                   | 54.2 | AVNS-TL | 28.0    | –                        | –    | –      | –     | –     | 851.4                | 53.2 | 5022.5 | <b>703.1</b>  | 43.3 | 720.3  | 8.9  | 222.2  |
| E5       | 403.6           | 1018.0                  | 60.4 | AVNS-TL | 28.0    | –                        | –    | –      | –     | –     | 905.4                | 55.4 | 5837.6 | <b>760.5</b>  | 46.9 | 777.2  | 11.0 | 217.2  |
| E6       | 404.5           | 1003.0                  | 59.7 | AVNS-TL | 28.0    | –                        | –    | –      | –     | –     | 878.8                | 54.0 | 4723.3 | <b>772.1</b>  | 47.6 | 788.4  | 8.6  | 223.3  |
| E7       | 384.7           | 921.1                   | 58.2 | AVNS-TL | 29.4    | –                        | –    | –      | –     | –     | 832.9                | 53.8 | 3319.7 | <b>708.8</b>  | 45.7 | 720.7  | 5.8  | 231.2  |
| E8       | 425.9           | 884.6                   | 51.9 | AVNS-TL | 28.0    | –                        | –    | –      | –     | –     | 832.7                | 48.9 | 4365.4 | <b>725.6</b>  | 41.3 | 743.6  | 8.9  | 217.1  |
| E9       | 431.2           | 1131.7                  | 61.9 | AVNS-TL | 26.5    | –                        | –    | –      | –     | –     | 1129.1               | 61.8 | 1530.0 | <b>877.1</b>  | 50.8 | 913.8  | 16.2 | 213.4  |
| E10      | 441.8           | 1053.6                  | 58.1 | LS      | 16.2    | –                        | –    | –      | –     | –     | 1026.8               | 57.0 | 3433.8 | <b>815.0</b>  | 45.8 | 828.2  | 9.8  | 219.6  |
|          | 418.1           | 1057.6                  | 60.5 |         | 24.4    | –                        | –    | –      | –     | –     | 966.1                | 56.7 | 4101.3 | <b>829.0</b>  | 49.6 | 846.8  | 10.4 | 219.8  |
| F1       | 546.7           | 1721.4                  | 68.2 | AVNS    | 1308.5  | –                        | –    | –      | –     | –     | –                    | –    | –      | <b>1342.1</b> | 59.3 | 1373.7 | 19.0 | 535.8  |
| F2       | 535.0           | 1763.8                  | 69.7 | AVNS    | 1337.9  | –                        | –    | –      | –     | –     | –                    | –    | –      | <b>1296.0</b> | 58.7 | 1322.8 | 16.7 | 564.1  |
| F3       | 541.6           | 1549.6                  | 65.0 | AVNS    | 1277.6  | –                        | –    | –      | –     | –     | –                    | –    | –      | <b>1201.1</b> | 54.9 | 1228.5 | 11.9 | 549.0  |
| F4       | 524.0           | 1420.4                  | 63.1 | AVNS    | 1944.3  | –                        | –    | –      | –     | –     | –                    | –    | –      | <b>1093.9</b> | 52.1 | 1107.6 | 14.4 | 640.9  |
| F5       | 529.0           | 1701.9                  | 68.9 | AVNS    | 1685.3  | –                        | –    | –      | –     | –     | –                    | –    | –      | <b>1286.8</b> | 58.9 | 1317.0 | 16.2 | 592.3  |
| F6       | 498.6           | 1639.7                  | 69.6 | AVNS    | 1230.5  | –                        | –    | –      | –     | –     | –                    | –    | –      | <b>1295.6</b> | 61.5 | 1315.5 | 10.8 | 522.5  |
| F7       | 502.5           | 1384.3                  | 63.7 | AVNS    | 1904.6  | –                        | –    | –      | –     | –     | –                    | –    | –      | <b>1088.2</b> | 53.8 | 1119.1 | 18.5 | 624.7  |
| F8       | 532.9           | 1544.6                  | 65.5 | AVNS    | 1360.0  | –                        | –    | –      | –     | –     | –                    | –    | –      | <b>1098.7</b> | 51.5 | 1131.1 | 12.4 | 566.3  |
| F9       | 535.9           | 1572.9                  | 65.9 | AVNS    | 2416.8  | –                        | –    | –      | –     | –     | –                    | –    | –      | <b>1262.1</b> | 57.5 | 1291.4 | 19.1 | 594.0  |
| F10      | 540.2           | 1581.0                  | 65.8 | AVNS    | 1951.7  | –                        | –    | –      | –     | –     | –                    | –    | –      | <b>1358.0</b> | 60.2 | 1392.6 | 14.2 | 582.4  |
|          | 528.6           | 1588.0                  | 66.7 |         | 1641.7  | –                        | –    | –      | –     | –     | –                    | –    | –      | <b>1232.3</b> | 57.1 | 1259.9 | 15.3 | 577.2  |
| G1       | 584.6           | 2248.0                  | 74.0 | AVNS    | 10597.5 | –                        | –    | –      | –     | –     | –                    | –    | –      | <b>1728.3</b> | 66.2 | 1749.3 | 20.4 | 1198.9 |
| G2       | 600.6           | 2316.1                  | 74.1 | AVNS    | 10597.5 | –                        | –    | –      | –     | –     | –                    | –    | –      | <b>1714.0</b> | 65.0 | 1771.0 | 21.7 | 1297.8 |
| G3       | 584.8           | 1885.3                  | 69.0 | AVNS    | 10519.5 | –                        | –    | –      | –     | –     | –                    | –    | –      | <b>1441.9</b> | 59.4 | 1474.4 | 15.7 | 1180.6 |

Table C3: Continued.

| Instance | LB <sup>+</sup> | Mankowska et al. (2014) |      |        |         | Lasfargeas et al. (2019) |     |      |    |      | Kummer et al. (2019) |     |      | BRKGA-MP-IPR  |      |        |      |        |
|----------|-----------------|-------------------------|------|--------|---------|--------------------------|-----|------|----|------|----------------------|-----|------|---------------|------|--------|------|--------|
|          |                 | Best                    | Gap  | Method | Time    | Best                     | Gap | Mean | SD | Time | Best                 | Gap | Time | Best          | Gap  | Mean   | SD   | Time   |
| G4       | 591.9           | 2023.2                  | 70.7 | AVNS   | 10597.5 | –                        | –   | –    | –  | –    | –                    | –   | –    | <b>1490.1</b> | 60.3 | 1523.1 | 19.0 | 1345.7 |
| G5       | 616.5           | 2247.6                  | 72.6 | AVNS   | 10597.5 | –                        | –   | –    | –  | –    | –                    | –   | –    | <b>1623.4</b> | 62.0 | 1650.9 | 23.2 | 1137.4 |
| G6       | 583.5           | 2144.4                  | 72.8 | AVNS   | 10597.5 | –                        | –   | –    | –  | –    | –                    | –   | –    | <b>1657.5</b> | 64.8 | 1682.8 | 18.0 | 1408.2 |
| G7       | 604.8           | 1971.5                  | 69.3 | AVNS   | 10206.0 | –                        | –   | –    | –  | –    | –                    | –   | –    | <b>1569.0</b> | 61.5 | 1590.6 | 14.4 | 1210.5 |
| G8       | 618.3           | 1987.4                  | 68.9 | AVNS   | 10597.5 | –                        | –   | –    | –  | –    | –                    | –   | –    | <b>1477.6</b> | 58.2 | 1503.0 | 17.0 | 1185.1 |
| G9       | 637.4           | 2415.5                  | 73.6 | AVNS   | 10337.0 | –                        | –   | –    | –  | –    | –                    | –   | –    | <b>1827.7</b> | 65.1 | 1880.3 | 38.1 | 1210.9 |
| G10      | 621.0           | 2373.4                  | 73.8 | AVNS   | 10307.5 | –                        | –   | –    | –  | –    | –                    | –   | –    | <b>1797.1</b> | 65.4 | 1822.4 | 16.6 | 1110.0 |
|          | 604.3           | 2161.2                  | 72.0 |        | 10495.5 | –                        | –   | –    | –  | –    | –                    | –   | –    | <b>1632.7</b> | 63.0 | 1664.8 | 20.4 | 1228.5 |



## Extended results for BRKGA, BRKGA-TL and BRKGA-MP-IPR

Table D4: Comparison of a simpler variant of BRKGA and BRKGA-MP-IPR. Values in bold indicate the best-known solution value produced by the methods, and values marked with an asterisk indicate an optimal solution value.

| Inst. | LB <sup>+</sup> | K2020         |             |        |            |      |       | BRKGA-TL      |             |        |            |      |             |       |         | BRKGA-MP-IPR |               |             |        |            |     |             |                |       |
|-------|-----------------|---------------|-------------|--------|------------|------|-------|---------------|-------------|--------|------------|------|-------------|-------|---------|--------------|---------------|-------------|--------|------------|-----|-------------|----------------|-------|
|       |                 | Best          | Gap (best)  | Mean   | Gap (mean) | SD   | Time  | Best          | Gap (best)  | Mean   | Gap (mean) | SD   | Diff. K2020 | Time  | Gens.   | LI gen.      | Best          | Gap         | Mean   | Gap (mean) | SD  | Diff. K2020 | Diff. BRKGA-TL | Time  |
| A1    | *218.2          | <b>227.0</b>  | <b>3.9</b>  | 227.0  | 3.9        | 0.0  | 2.8   | <b>227.0</b>  | <b>3.9</b>  | 227.0  | 3.9        | 0.0  | 0.0         | 81.2  | 144,111 | 10.5         | <b>227.0</b>  | <b>3.9</b>  | 227.0  | 3.9        | 0.0 | 0.0         | 0.0            | 98.6  |
| A2    | *246.6          | <b>*246.6</b> | <b>0.0</b>  | 246.6  | 0.0        | 0.0  | 2.7   | <b>*246.6</b> | <b>0.0</b>  | 246.6  | 0.0        | 0.0  | 0.0         | 79.5  | 140,266 | 10.9         | <b>*246.6</b> | <b>0.0</b>  | 246.6  | 0.0        | 0.0 | 0.0         | 0.0            | 97.3  |
| A3    | *305.9          | <b>*305.9</b> | <b>0.0</b>  | 305.9  | 0.0        | 0.0  | 2.7   | <b>*305.9</b> | <b>0.0</b>  | 305.9  | 0.0        | 0.0  | 0.0         | 79.6  | 143,560 | 7.8          | <b>*305.9</b> | <b>0.0</b>  | 305.9  | 0.0        | 0.0 | 0.0         | 0.0            | 99.6  |
| A4    | *186.9          | <b>*186.9</b> | <b>0.0</b>  | 186.9  | 0.0        | 0.0  | 2.7   | <b>*186.9</b> | <b>0.0</b>  | 186.9  | 0.0        | 0.0  | 0.0         | 79.9  | 145,238 | 7.9          | <b>*186.9</b> | <b>0.0</b>  | 186.9  | 0.0        | 0.0 | 0.0         | 0.0            | 97.6  |
| A5    | *189.5          | <b>192.0</b>  | <b>1.3</b>  | 192.0  | 1.3        | 0.0  | 2.8   | <b>192.0</b>  | <b>1.3</b>  | 192.0  | 1.3        | 0.0  | 0.0         | 79.7  | 138,962 | 8.5          | <b>192.0</b>  | <b>1.3</b>  | 192.0  | 1.3        | 0.0 | 0.0         | 0.0            | 97.4  |
| A6    | *200.1          | <b>*200.1</b> | <b>0.0</b>  | 200.1  | 0.0        | 0.0  | 2.8   | <b>*200.1</b> | <b>0.0</b>  | 200.1  | 0.0        | 0.0  | 0.0         | 79.7  | 140,048 | 9.9          | <b>*200.1</b> | <b>0.0</b>  | 200.1  | 0.0        | 0.0 | 0.0         | 0.0            | 98.1  |
| A7    | *225.4          | <b>*225.4</b> | <b>0.0</b>  | 225.4  | 0.0        | 0.0  | 2.5   | <b>*225.4</b> | <b>0.0</b>  | 225.4  | 0.0        | 0.0  | 0.0         | 80.1  | 154,205 | 10.9         | <b>*225.4</b> | <b>0.0</b>  | 225.4  | 0.0        | 0.0 | 0.0         | 0.0            | 97.2  |
| A8    | *232.0          | <b>*232.0</b> | <b>0.0</b>  | 232.0  | 0.0        | 0.0  | 2.5   | <b>*232.1</b> | <b>0.0</b>  | 232.0  | 0.0        | 0.0  | 0.0         | 79.6  | 152,986 | 9.7          | <b>*232.1</b> | <b>0.0</b>  | 232.1  | 0.0        | 0.0 | 0.0         | 0.0            | 98.4  |
| A9    | *222.3          | <b>234.2</b>  | <b>5.1</b>  | 234.2  | 5.1        | 0.0  | 3.0   | <b>234.2</b>  | <b>5.1</b>  | 234.2  | 5.1        | 0.0  | 0.0         | 80.1  | 130,577 | 11.3         | <b>234.2</b>  | <b>5.1</b>  | 234.2  | 5.1        | 0.0 | 0.0         | 0.0            | 96.5  |
| A10   | *225.0          | <b>*225.0</b> | <b>0.0</b>  | 225.0  | 0.0        | 0.0  | 2.6   | <b>*225.0</b> | <b>0.0</b>  | 225.0  | 0.0        | 0.0  | 0.0         | 78.6  | 151,484 | 4.2          | <b>*225.0</b> | <b>0.0</b>  | 225.0  | 0.0        | 0.0 | 0.0         | 0.0            | 96.2  |
|       | 225.2           | <b>227.5</b>  | <b>1.0</b>  | 227.5  | 1.0        | 0.0  | 2.7   | <b>227.5</b>  | <b>1.0</b>  | 227.5  | 1.0        | 0.0  | 0.0         | 79.8  | 144,144 | 9.2          | <b>227.5</b>  | <b>1.0</b>  | 227.5  | 1.0        | 0.0 | 0.0         | 0.0            | 97.7  |
| B1    | *428.1          | <b>*428.1</b> | <b>0.0</b>  | 428.3  | 0.0        | 0.2  | 10.0  | <b>*428.1</b> | <b>0.0</b>  | 428.1  | 0.0        | 0.0  | 0.0         | 90.2  | 57,618  | 2470.3       | <b>*428.1</b> | <b>0.0</b>  | 428.1  | 0.0        | 0.0 | 0.0         | 0.0            | 103.9 |
| B2    | *476.0          | <b>483.6</b>  | <b>1.6</b>  | 485.7  | 2.0        | 1.5  | 9.7   | <b>483.6</b>  | <b>1.6</b>  | 485.7  | 2.0        | 1.5  | 0.0         | 89.8  | 58,918  | 171.4        | <b>483.6</b>  | <b>1.6</b>  | 483.6  | 1.6        | 0.0 | 0.0         | 0.0            | 105.5 |
| B3    | 371.4           | <b>402.8</b>  | <b>7.8</b>  | 402.8  | 7.8        | 0.0  | 10.4  | <b>402.8</b>  | <b>7.8</b>  | 402.8  | 7.8        | 0.0  | 0.0         | 90.5  | 55,058  | 187.1        | <b>402.8</b>  | <b>7.8</b>  | 402.8  | 7.8        | 0.0 | 0.0         | 0.0            | 104.4 |
| B4    | *411.3          | <b>420.3</b>  | <b>2.1</b>  | 431.9  | 4.8        | 3.5  | 9.5   | <b>420.3</b>  | <b>2.1</b>  | 425.4  | 3.3        | 6.5  | 0.0         | 89.9  | 60,078  | 7435.7       | <b>420.3</b>  | <b>2.1</b>  | 429.1  | 4.2        | 5.3 | 0.0         | 0.0            | 105.9 |
| B5    | 363.7           | <b>372.2</b>  | <b>2.3</b>  | 374.2  | 2.8        | 3.0  | 9.5   | <b>372.2</b>  | <b>2.3</b>  | 373.6  | 2.7        | 2.5  | 0.0         | 89.9  | 60,923  | 2307.1       | <b>372.2</b>  | <b>2.3</b>  | 373.0  | 2.5        | 2.2 | 0.0         | 0.0            | 102.2 |
| B6    | 372.8           | <b>471.0</b>  | <b>20.8</b> | 471.9  | 21.0       | 1.4  | 10.3  | <b>471.0</b>  | <b>20.8</b> | 471.4  | 20.9       | 1.4  | 0.0         | 90.5  | 54,797  | 6886.4       | <b>471.0</b>  | <b>20.8</b> | 471.0  | 20.8       | 0.0 | 0.0         | 0.0            | 107.8 |
| B7    | *328.6          | <b>*328.7</b> | <b>0.0</b>  | 328.7  | 0.0        | 0.0  | 11.0  | <b>*328.7</b> | <b>0.0</b>  | 328.7  | 0.0        | 0.0  | 0.0         | 90.7  | 53,635  | 78.6         | <b>*328.7</b> | <b>0.0</b>  | 328.7  | 0.0        | 0.0 | 0.0         | 0.0            | 104.5 |
| B8    | *357.6          | <b>359.7</b>  | <b>0.6</b>  | 359.7  | 0.6        | 0.0  | 10.6  | <b>359.7</b>  | <b>0.6</b>  | 359.7  | 0.6        | 0.0  | 0.0         | 90.5  | 53,849  | 48.7         | <b>359.7</b>  | <b>0.6</b>  | 359.7  | 0.6        | 0.0 | 0.0         | 0.0            | 106.0 |
| B9    | 336.9           | <b>402.7</b>  | <b>16.3</b> | 404.3  | 16.7       | 1.1  | 11.5  | <b>402.7</b>  | <b>16.3</b> | 403.1  | 16.4       | 0.9  | 0.0         | 91.5  | 50,479  | 14350.3      | <b>402.7</b>  | <b>16.3</b> | 403.2  | 16.4       | 0.7 | 0.0         | 0.0            | 107.3 |
| B10   | 413.7           | <b>469.6</b>  | <b>11.9</b> | 469.6  | 11.9       | 0.0  | 10.6  | <b>469.6</b>  | <b>11.9</b> | 469.6  | 11.9       | 0.0  | 0.0         | 91.0  | 53,094  | 73.6         | <b>469.6</b>  | <b>11.9</b> | 469.6  | 11.9       | 0.0 | 0.0         | 0.0            | 106.8 |
|       | 386.0           | <b>413.9</b>  | <b>6.7</b>  | 415.7  | 6.8        | 1.1  | 10.3  | <b>413.9</b>  | <b>6.7</b>  | 414.8  | 6.6        | 1.3  | 0.0         | 90.5  | 55,845  | 3400.9       | <b>413.9</b>  | <b>6.7</b>  | 414.9  | 6.6        | 0.8 | 0.0         | 0.0            | 105.4 |
| C1    | 477.3           | <b>965.2</b>  | <b>50.5</b> | 975.6  | 51.1       | 7.6  | 42.8  | <b>965.2</b>  | <b>50.5</b> | 973.9  | 51.0       | 7.4  | 0.0         | 121.0 | 20,399  | 4476.7       | <b>965.2</b>  | <b>50.5</b> | 966.6  | 50.6       | 1.9 | 0.0         | 0.0            | 127.2 |
| C2    | 377.4           | 583.4         | 35.3        | 590.5  | 36.1       | 9.9  | 45.2  | <b>582.2</b>  | <b>35.2</b> | 585.8  | 35.6       | 5.8  | -0.2        | 120.2 | 19,441  | 8723.3       | <b>582.2</b>  | <b>35.2</b> | 582.9  | 35.2       | 1.2 | -0.2        | 0.0            | 135.4 |
| C3    | 396.4           | <b>548.8</b>  | <b>27.8</b> | 559.1  | 29.1       | 6.8  | 43.3  | <b>548.8</b>  | <b>27.8</b> | 556.1  | 28.7       | 5.7  | 0.0         | 119.1 | 20,378  | 4610.9       | <b>548.8</b>  | <b>27.8</b> | 551.4  | 28.1       | 1.5 | 0.0         | 0.0            | 130.2 |
| C4    | 367.4           | <b>519.9</b>  | <b>29.3</b> | 530.6  | 30.8       | 7.0  | 41.9  | <b>519.9</b>  | <b>29.3</b> | 525.8  | 30.1       | 4.0  | 0.0         | 117.8 | 20,637  | 6730.3       | <b>519.8</b>  | <b>29.3</b> | 523.2  | 29.8       | 2.5 | 0.0         | 0.0            | 127.6 |
| C5    | 496.9           | 678.6         | 26.8        | 702.9  | 29.3       | 20.7 | 36.4  | <b>670.6</b>  | <b>25.9</b> | 689.8  | 28.0       | 19.2 | -1.2        | 114.6 | 23,978  | 7658.3       | <b>670.6</b>  | <b>25.9</b> | 675.3  | 26.4       | 4.4 | -1.2        | 0.0            | 130.1 |
| C6    | 366.1           | <b>840.7</b>  | <b>56.4</b> | 845.5  | 56.7       | 5.0  | 43.1  | <b>840.7</b>  | <b>56.4</b> | 843.5  | 56.6       | 3.2  | 0.0         | 119.3 | 20,032  | 3166.6       | <b>840.7</b>  | <b>56.4</b> | 842.4  | 56.5       | 1.4 | 0.0         | 0.0            | 128.2 |
| C7    | 365.2           | 534.9         | 31.7        | 540.4  | 32.4       | 5.4  | 48.9  | <b>528.5</b>  | <b>30.9</b> | 536.8  | 32.0       | 5.4  | -1.2        | 124.0 | 18,097  | 4447.8       | <b>528.5</b>  | <b>30.9</b> | 532.5  | 31.4       | 3.4 | -1.2        | 0.0            | 133.5 |
| C8    | 377.1           | 474.6         | 20.5        | 480.1  | 21.5       | 4.0  | 42.3  | 473.3         | 20.3        | 477.4  | 21.0       | 3.5  | -0.3        | 118.1 | 20,720  | 6047.9       | <b>472.0</b>  | <b>20.1</b> | 475.1  | 20.6       | 1.5 | -0.5        | -0.3           | 133.5 |
| C9    | 361.5           | 534.3         | 32.3        | 551.1  | 34.4       | 8.8  | 49.6  | 533.9         | 32.3        | 545.1  | 33.7       | 7.0  | -0.1        | 123.3 | 18,149  | 4990.6       | <b>531.2</b>  | <b>31.9</b> | 538.7  | 32.9       | 4.5 | -0.6        | -0.5           | 130.7 |
| C10   | 449.8           | 611.3         | 26.4        | 618.3  | 27.2       | 4.7  | 40.9  | 611.3         | 26.4        | 615.3  | 26.9       | 3.3  | 0.0         | 126.2 | 23,021  | 8315.3       | <b>610.9</b>  | <b>26.4</b> | 612.3  | 26.5       | 2.0 | -0.1        | -0.1           | 130.2 |
|       | 403.5           | 629.1         | 35.9        | 639.4  | 34.9       | 8.0  | 43.5  | 627.4         | 35.7        | 635.0  | 34.4       | 6.5  | -0.3        | 120.4 | 20,485  | 5916.8       | <b>627.0</b>  | <b>35.6</b> | 630.0  | 33.8       | 2.4 | -0.4        | -0.1           | 130.7 |
| D1    | 514.4           | 1186.2        | 56.6        | 1209.6 | 57.5       | 15.8 | 108.6 | 1186.2        | 56.6        | 1207.4 | 57.4       | 13.7 | 0.0         | 164.8 | 11,318  | 4618.9       | <b>1179.9</b> | <b>56.4</b> | 1195.9 | 57.0       | 7.1 | -0.5        | -0.5           | 169.3 |

Table D4: Continued.

| Inst. | LB <sup>+</sup> | K2020  |            |        |            |      |        | BRKGA-TL     |             |        |            |      |             |        |        | BRKGA-MP-IPR |               |             |        |            |      |             |                |        |
|-------|-----------------|--------|------------|--------|------------|------|--------|--------------|-------------|--------|------------|------|-------------|--------|--------|--------------|---------------|-------------|--------|------------|------|-------------|----------------|--------|
|       |                 | Best   | Gap (best) | Mean   | Gap (mean) | SD   | Time   | Best         | Gap (best)  | Mean   | Gap (mean) | SD   | Diff. K2020 | Time   | Gens.  | LI gen.      | Best          | Gap         | Mean   | Gap (mean) | SD   | Diff. K2020 | Diff. BRKGA-TL | Time   |
| D2    | 386.0           | 693.3  | 44.3       | 718.0  | 46.2       | 17.3 | 96.1   | 685.9        | 43.7        | 709.2  | 45.6       | 16.2 | -1.1        | 156.5  | 13,018 | 4916.3       | <b>684.3</b>  | <b>43.6</b> | 694.8  | 44.4       | 7.3  | -1.3        | -0.2           | 155.5  |
| D3    | 379.5           | 635.7  | 40.3       | 651.4  | 41.7       | 8.2  | 118.5  | 635.7        | 40.3        | 647.6  | 41.4       | 6.3  | 0.0         | 170.9  | 10,945 | 4311.0       | <b>633.4</b>  | <b>40.1</b> | 640.6  | 40.8       | 4.0  | -0.4        | -0.4           | 170.2  |
| D4    | 408.5           | 814.3  | 49.8       | 841.6  | 51.5       | 11.6 | 95.4   | 804.5        | 49.2        | 838.7  | 51.3       | 13.6 | -1.2        | 156.3  | 12,974 | 4484.1       | <b>804.4</b>  | <b>49.2</b> | 829.6  | 50.8       | 14.2 | -1.2        | 0.0            | 159.8  |
| D5    | 404.3           | 691.5  | 41.5       | 703.1  | 42.5       | 13.5 | 107.1  | 689.4        | 41.4        | 701.3  | 42.4       | 13.8 | -0.3        | 164.1  | 11,514 | 3885.3       | <b>682.8</b>  | <b>40.8</b> | 691.8  | 41.6       | 4.6  | -1.3        | -1.0           | 165.5  |
| D6    | 391.8           | 733.7  | 46.6       | 744.7  | 47.4       | 7.1  | 122.7  | 731.3        | 46.4        | 742.0  | 47.2       | 7.4  | -0.3        | 174.3  | 10,430 | 3473.4       | <b>712.1</b>  | <b>45.0</b> | 727.6  | 46.1       | 6.5  | -2.9        | -2.6           | 170.7  |
| D7    | 359.0           | 590.6  | 39.2       | 604.7  | 40.6       | 6.9  | 130.8  | 590.6        | 39.2        | 604.0  | 40.6       | 6.5  | 0.0         | 177.6  | 10,333 | 3031.7       | <b>585.6</b>  | <b>38.7</b> | 592.4  | 39.4       | 5.0  | -0.9        | -0.9           | 177.8  |
| D8    | 406.8           | 661.8  | 38.5       | 680.3  | 40.2       | 11.4 | 119.0  | <b>657.8</b> | <b>38.2</b> | 676.9  | 39.9       | 11.9 | -0.6        | 171.0  | 10,824 | 3695.6       | 658.4         | 38.2        | 663.3  | 38.7       | 3.0  | -0.5        | 0.1            | 171.2  |
| D9    | 387.6           | 706.1  | 45.1       | 723.4  | 46.4       | 10.2 | 107.3  | 704.5        | 45.0        | 721.6  | 46.3       | 10.6 | -0.2        | 164.0  | 11,619 | 4810.7       | <b>696.2</b>  | <b>44.3</b> | 713.7  | 45.7       | 12.1 | -1.4        | -1.2           | 162.4  |
| D10   | 479.3           | 1208.7 | 60.3       | 1290.6 | 62.9       | 72.5 | 90.1   | 1205.8       | 60.2        | 1276.0 | 62.4       | 71.6 | -0.2        | 153.2  | 13,543 | 6668.4       | <b>1201.7</b> | <b>60.1</b> | 1223.5 | 60.8       | 21.1 | -0.6        | -0.3           | 156.8  |
|       | 411.7           | 792.2  | 48.0       | 816.8  | 47.7       | 17.4 | 109.6  | 789.2        | 47.8        | 812.5  | 47.4       | 17.2 | -0.4        | 165.3  | 11,652 | 4389.5       | <b>783.9</b>  | <b>47.5</b> | 797.3  | 46.5       | 8.5  | -1.1        | -0.7           | 165.9  |
| E1    | 421.8           | 1331.5 | 68.3       | 1352.3 | 68.8       | 11.2 | 224.4  | 1329.0       | 68.3        | 1348.2 | 68.7       | 11.5 | -0.2        | 234.6  | 8,087  | 4368.5       | <b>1318.9</b> | <b>68.0</b> | 1335.1 | 68.4       | 10.6 | -0.9        | -0.8           | 219.0  |
| E2    | 423.7           | 848.1  | 50.0       | 871.2  | 51.4       | 16.6 | 222.6  | 842.3        | 49.7        | 867.5  | 51.2       | 15.1 | -0.7        | 231.8  | 8,358  | 3291.6       | <b>824.2</b>  | <b>48.6</b> | 846.1  | 49.9       | 16.6 | -2.8        | -2.2           | 218.1  |
| E3    | 445.2           | 788.0  | 43.5       | 814.2  | 45.3       | 16.8 | 212.0  | 785.8        | 43.3        | 809.8  | 45.0       | 15.4 | -0.3        | 227.2  | 8,358  | 3901.9       | <b>785.1</b>  | <b>43.3</b> | 794.4  | 44.0       | 7.4  | -0.4        | -0.1           | 216.9  |
| E4    | 398.5           | 711.2  | 44.0       | 729.9  | 45.4       | 12.7 | 227.8  | 709.0        | 43.8        | 726.8  | 45.2       | 12.6 | -0.3        | 234.2  | 7,945  | 4666.2       | <b>703.1</b>  | <b>43.3</b> | 720.3  | 44.7       | 8.9  | -1.1        | -0.8           | 222.2  |
| E5    | 403.6           | 781.5  | 48.4       | 803.9  | 49.8       | 13.8 | 211.3  | 772.9        | 47.8        | 793.8  | 49.2       | 12.5 | -1.1        | 226.8  | 8,525  | 5031.1       | <b>760.5</b>  | <b>46.9</b> | 777.2  | 48.1       | 11.0 | -2.7        | -1.6           | 217.2  |
| E6    | 404.5           | 790.5  | 48.8       | 804.2  | 49.7       | 8.0  | 205.9  | 785.4        | 48.5        | 801.0  | 49.5       | 8.7  | -0.6        | 233.7  | 7,958  | 4135.4       | <b>772.1</b>  | <b>47.6</b> | 788.4  | 48.7       | 8.6  | -2.3        | -1.7           | 223.3  |
| E7    | 384.7           | 711.1  | 45.9       | 733.9  | 47.6       | 8.9  | 222.4  | <b>707.3</b> | <b>45.6</b> | 730.8  | 47.4       | 9.8  | -0.5        | 246.6  | 7,705  | 4444.1       | 708.8         | 45.7        | 720.7  | 46.6       | 5.8  | -0.3        | 0.2            | 231.2  |
| E8    | 425.9           | 752.4  | 43.4       | 762.0  | 44.1       | 7.2  | 195.7  | 749.3        | 43.2        | 758.9  | 43.9       | 7.3  | -0.4        | 226.4  | 8,325  | 3789.7       | <b>725.6</b>  | <b>41.3</b> | 743.6  | 42.7       | 8.9  | -3.6        | -3.2           | 217.1  |
| E9    | 431.2           | 921.8  | 53.2       | 951.9  | 54.7       | 13.9 | 189.1  | 910.7        | 52.6        | 944.1  | 54.3       | 14.2 | -1.2        | 224.1  | 8,691  | 4906.3       | <b>877.1</b>  | <b>50.8</b> | 913.8  | 52.8       | 16.2 | -4.8        | -3.7           | 213.4  |
| E10   | 441.8           | 825.2  | 46.5       | 845.1  | 47.7       | 14.7 | 202.3  | 819.3        | 46.1        | 842.3  | 47.5       | 15.7 | -0.7        | 233.0  | 8,351  | 4819.1       | <b>815.0</b>  | <b>45.8</b> | 828.2  | 46.7       | 9.8  | -1.2        | -0.5           | 219.6  |
|       | 418.1           | 846.1  | 50.6       | 866.9  | 50.5       | 12.4 | 211.3  | 841.1        | 50.3        | 862.3  | 50.2       | 12.3 | -0.6        | 231.9  | 8,230  | 4335.4       | <b>829.0</b>  | <b>49.6</b> | 846.8  | 49.3       | 10.4 | -2.0        | -1.4           | 219.8  |
| F1    | 546.7           | 1402.0 | 61.0       | 1426.0 | 61.7       | 14.4 | 864.3  | 1396.5       | 60.8        | 1416.2 | 61.4       | 12.2 | -0.4        | 618.1  | 5,379  | 4317.5       | <b>1342.1</b> | <b>59.3</b> | 1373.7 | 60.2       | 19.0 | -4.3        | -3.9           | 535.8  |
| F2    | 535.0           | 1336.3 | 60.0       | 1383.6 | 61.3       | 26.1 | 941.5  | 1322.3       | 59.5        | 1367.5 | 60.9       | 25.2 | -1.0        | 651.6  | 5,234  | 4223.3       | <b>1296.0</b> | <b>58.7</b> | 1322.8 | 59.6       | 16.7 | -3.0        | -2.0           | 564.1  |
| F3    | 541.6           | 1263.4 | 57.1       | 1285.8 | 57.9       | 12.6 | 904.7  | 1258.0       | 56.9        | 1281.1 | 57.7       | 13.3 | -0.4        | 628.0  | 5,302  | 3665.1       | <b>1201.1</b> | <b>54.9</b> | 1228.5 | 55.9       | 11.9 | -4.9        | -4.5           | 549.0  |
| F4    | 524.0           | 1124.2 | 53.4       | 1146.2 | 54.3       | 11.9 | 1045.7 | 1123.4       | 53.4        | 1141.6 | 54.1       | 10.3 | -0.1        | 733.8  | 5,135  | 3702.7       | <b>1093.9</b> | <b>52.1</b> | 1107.6 | 52.7       | 14.4 | -2.7        | -2.6           | 640.9  |
| F5    | 529.0           | 1329.3 | 60.2       | 1365.2 | 61.2       | 20.0 | 957.8  | 1322.1       | 60.0        | 1355.2 | 61.0       | 21.0 | -0.5        | 682.0  | 5,103  | 4068.9       | <b>1286.8</b> | <b>58.9</b> | 1317.0 | 59.8       | 16.2 | -3.2        | -2.7           | 592.3  |
| F6    | 498.6           | 1332.1 | 62.6       | 1373.3 | 63.7       | 24.3 | 753.3  | 1330.8       | 62.5        | 1366.1 | 63.5       | 22.5 | -0.1        | 597.1  | 5,525  | 3814.8       | <b>1295.6</b> | <b>61.5</b> | 1315.5 | 62.1       | 10.8 | -2.7        | -2.6           | 522.5  |
| F7    | 502.5           | 1131.3 | 55.6       | 1157.4 | 56.6       | 14.2 | 947.2  | 1125.0       | 55.3        | 1149.4 | 56.3       | 15.0 | -0.6        | 719.0  | 5,093  | 4266.5       | <b>1088.2</b> | <b>53.8</b> | 1119.1 | 55.1       | 18.5 | -3.8        | -3.3           | 624.7  |
| F8    | 532.9           | 1132.8 | 53.0       | 1165.1 | 54.3       | 18.1 | 830.5  | 1125.4       | 52.6        | 1160.1 | 54.1       | 17.4 | -0.7        | 654.5  | 5,230  | 3942.7       | <b>1098.7</b> | <b>51.5</b> | 1131.1 | 52.9       | 12.4 | -3.0        | -2.4           | 566.3  |
| F9    | 535.9           | 1311.4 | 59.1       | 1345.0 | 60.2       | 18.0 | 893.2  | 1304.2       | 58.9        | 1336.5 | 59.9       | 19.1 | -0.5        | 686.2  | 5,145  | 3599.5       | <b>1262.1</b> | <b>57.5</b> | 1291.4 | 58.5       | 19.1 | -3.8        | -3.2           | 594.0  |
| F10   | 540.2           | 1418.5 | 61.9       | 1446.3 | 62.6       | 17.1 | 858.3  | 1405.1       | 61.6        | 1438.1 | 62.4       | 17.0 | -0.9        | 670.9  | 5,132  | 4069.4       | <b>1358.0</b> | <b>60.2</b> | 1392.6 | 61.2       | 14.2 | -4.3        | -3.4           | 582.4  |
|       | 528.6           | 1278.1 | 58.6       | 1309.4 | 59.4       | 17.7 | 899.6  | 1271.3       | 58.4        | 1301.2 | 59.1       | 17.3 | -0.5        | 664.1  | 5,228  | 3967.0       | <b>1232.3</b> | <b>57.1</b> | 1259.9 | 57.8       | 15.3 | -3.6        | -3.1           | 577.2  |
| G1    | 584.6           | 1778.5 | 67.1       | 1855.2 | 68.5       | 35.4 | 2260.5 | 1762.6       | 66.8        | 1837.0 | 68.2       | 32.5 | -0.9        | 1370.6 | 4,636  | 4020.3       | <b>1728.3</b> | <b>66.2</b> | 1749.3 | 66.6       | 20.4 | -2.8        | -1.9           | 1198.9 |
| G2    | 600.6           | 1824.7 | 67.1       | 1898.0 | 68.4       | 37.6 | 2452.1 | 1811.6       | 66.8        | 1874.1 | 68.0       | 34.7 | -0.7        | 1524.4 | 4,570  | 4288.9       | <b>1714.0</b> | <b>65.0</b> | 1771.0 | 66.1       | 21.7 | -6.1        | -5.4           | 1297.8 |
| G3    | 584.8           | 1514.2 | 61.4       | 1546.5 | 62.2       | 15.7 | 2243.5 | 1501.1       | 61.0        | 1533.4 | 61.9       | 18.3 | -0.9        | 1347.2 | 4,678  | 4209.4       | <b>1441.9</b> | <b>59.4</b> | 1474.4 | 60.3       | 15.7 | -4.8        | -3.9           | 1180.6 |
| G4    | 591.9           | 1564.4 | 62.2       | 1599.4 | 63.0       | 23.9 | 2478.3 | 1551.3       | 61.8        | 1586.4 | 62.7       | 23.8 | -0.8        | 1562.6 | 4,668  | 4240.3       | <b>1490.1</b> | <b>60.3</b> | 1523.1 | 61.1       | 19.0 | -4.8        | -3.9           | 1345.7 |
| G5    | 616.5           | 1698.3 | 63.7       | 1749.1 | 64.8       | 26.5 | 2134.3 | 1680.5       | 63.3        | 1729.2 | 64.3       | 24.1 | -1.0        | 1335.8 | 4,712  | 4313.9       | <b>1623.4</b> | <b>62.0</b> | 1650.9 | 62.7       | 23.2 | -4.4        | -3.4           | 1137.4 |
| G6    | 583.5           | 1714.4 | 66.0       | 1777.4 | 67.2       | 24.4 | 2335.5 | 1701.2       | 65.7        | 1764.1 | 66.9       | 25.0 | -0.8        | 1629.8 | 4,559  | 4114.8       | <b>1657.5</b> | <b>64.8</b> | 1682.8 | 65.3       | 18.0 | -3.3        | -2.6           | 1408.2 |
| G7    | 604.8           | 1640.1 | 63.1       | 1677.9 | 64.0       | 24.4 | 2138.3 | 1625.0       | 62.8        | 1663.0 | 63.6       | 26.7 | -0.9        | 1402.6 | 4,706  | 4212.8       | <b>1569.0</b> | <b>61.5</b> | 1590.6 | 62.0       | 14.4 | -4.3        | -3.4           | 1210.5 |
| G8    | 618.3           | 1547.6 | 60.0       | 1583.9 | 61.0       | 20.5 | 2085.8 | 1532.9       | 59.7        | 1567.4 | 60.6       | 17.5 | -1.0        | 1390.4 | 4,789  | 4403.4       | <b>1477.6</b> | <b>58.2</b> | 1503.0 | 58.9       | 17.0 | -4.5        | -3.6           | 1185.1 |

Table D4: Continued.

| Inst. | LB <sup>+</sup> | K2020  |            |        |            |      |        | BRKGA-TL |            |        |            |      |             |        |       | BRKGA-MP-IPR |               |             |        |            |      |             |                |        |
|-------|-----------------|--------|------------|--------|------------|------|--------|----------|------------|--------|------------|------|-------------|--------|-------|--------------|---------------|-------------|--------|------------|------|-------------|----------------|--------|
|       |                 | Best   | Gap (best) | Mean   | Gap (mean) | SD   | Time   | Best     | Gap (best) | Mean   | Gap (mean) | SD   | Diff. K2020 | Time   | Gens. | LI gen.      | Best          | Gap         | Mean   | Gap (mean) | SD   | Diff. K2020 | Diff. BRKGA-TL | Time   |
| G9    | 637.4           | 1942.2 | 67.2       | 1972.5 | 67.7       | 21.1 | 2099.3 | 1932.6   | 67.0       | 1954.7 | 67.4       | 18.3 | -0.5        | 1429.9 | 4,731 | 4123.4       | <b>1827.7</b> | <b>65.1</b> | 1880.3 | 66.1       | 38.1 | -5.9        | -5.4           | 1210.9 |
| G10   | 621.0           | 1872.1 | 66.8       | 1932.3 | 67.9       | 28.2 | 1912.5 | 1855.9   | 66.5       | 1907.1 | 67.4       | 27.2 | -0.9        | 1277.3 | 4,747 | 4189.3       | <b>1797.1</b> | <b>65.4</b> | 1822.4 | 65.9       | 16.6 | -4.0        | -3.2           | 1110.0 |
|       | 604.3           | 1709.7 | 64.7       | 1759.2 | 65.4       | 25.8 | 2214.0 | 1695.5   | 64.4       | 1741.6 | 65.1       | 24.8 | -0.8        | 1427.1 | 4,680 | 4211.6       | <b>1632.7</b> | <b>63.0</b> | 1664.8 | 63.5       | 20.4 | -4.5        | -3.7           | 1228.5 |