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Report

Experiments on the Node, Edge, and Arc Routing Problem

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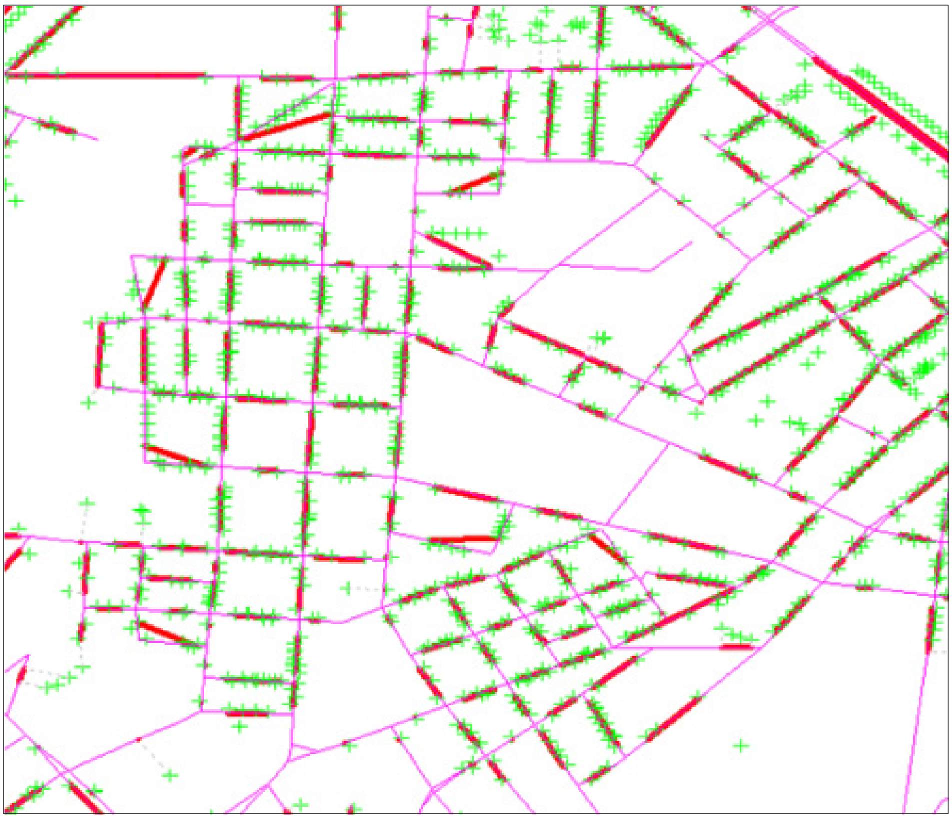

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ABSTRACT

Abstract

The Node, Edge, and Arc Routing Problem (NEARP) was defined by Prins and Bouchenoua in 2004 along with the first benchmark called CBMix. The NEARP generalizes the classical Capacitated Vehicle Routing Problem (CVRP), the Capacitated Arc Routing Problem (CARP), and the General Routing Problem. It is also denoted the Mixed Capacitated General Routing Problem (MCGRP). The NEARP removes the strict and unwarranted dichotomy that previously existed in the literature between arc routing and node routing. In real applications, there are many cases where the pure node or arc routing models are not adequate. In fundamentally node-based routing applications such as newspaper delivery and communal waste management that have typically been modeled as arc routing problems in the literature, the number of points is often so large that demand aggregation is necessary. Aggregation heuristics will normally give a NEARP instance, possibly with side constraints. Hence, the NEARP is a scientifically challenging problem with high industrial relevance. In this report we present experiments with Spider, SINTEF's industrial VRP solver, on the three NEARP benchmarks that have been published so far: CBMix, BHW, and DI-NEARP. Bach, Hasle, and Wøhlk have developed a combinatorial lower bound for the NEARP and defined the two latter benchmarks. Here, we present an experimental study with Spider on the three existing NEARP benchmarks. Upper and lower bounds are given for all instances. Three of the BHW instances have been solved to optimality. SINTEF has developed a web page for NEARP results on http://www.sintef.no/NEARP.

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Experiments on the Node, Edge, and Arc Routing Problem

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Abstract

The Node, Edge, and Arc Routing Problem (NEARP) was defined by Prins and Bouchenoua in 2004 along with the first benchmark called CBMix. The NEARP generalizes the classical Capacitated Vehicle Routing Problem (CVRP), the Capacitated Arc Routing Problem (CARP), and the General Routing Problem. It is also denoted the Mixed Capacitated General Routing Problem (MCGRP). The NEARP removes the strict and unwarranted dichotomy that previously existed in the literature between arc routing and node routing. In real applications, there are many cases where the pure node or arc routing models are not adequate. In fundamentally node-based routing applications such as newspaper delivery and communal waste management that have typically been modeled as arc routing problems in the literature, the number of points is often so large that demand aggregation is necessary. Aggregation heuristics will normally give a NEARP instance, possibly with side constraints. Hence, the NEARP is a scientifically challenging problem with high industrial relevance. In this report we present experiments with Spider, SINTEF's industrial VRP solver, on the three NEARP benchmarks that have been published so far: CBMix, BHW, and DI-NEARP. Bach, Hasle, and Wøhlk have developed a combinatorial lower bound for the NEARP and defined the two latter benchmarks. Here, we present an experimental study with Spider on the three existing NEARP benchmarks. Upper and lower bounds are given for all instances. Three of the BHW instances have been solved to optimality. SINTEF has developed a web page for NEARP results on `http://www.sintef.no/NEARP`.

Keywords: Vehicle Routing; Node Routing; Arc Routing; General Routing; VRP; CARP; NEARP; MCGRP; Bound; Benchmark; Experiment; Spider

1 Background

SINTEF's VRP solver Spider has a flexible and generic rich model that supports a variety of industrial cases and VRP variants in the literature. Through comparative empirical investigations, Spider has proven to have high performance not only for industrial cases [7], but also for several stylized VRP variants such as CVRP, VRPTW, and PDPTW [4]. The algorithm is basically a combination of Iterated Local Search (ILS) and Variable Neighborhood Descent (VND) that utilizes a large repertoire of constructors, local search operators, and diversifiers. These have been designed and extended to accommodate the rich VRP model. The sequence of local search operators in the VND is determined dynamically by roulette wheel selection where probabilities are changed based on improvement merits. We refer to [4] for details on the model and the algorithmic approach.

The Node, Edge, and Arc Routing Problem (NEARP) was defined by Prins and Bouchenoua in 2004 along with the first benchmark called CBMix. The NEARP generalizes the classical Capacitated Vehicle Routing Problem (CVRP), the Capacitated Arc Routing Problem (CARP), and the General Routing Problem. It is also denoted the Mixed Capacitated General Routing Problem (MCGRP). The NEARP removes the strict and unwarranted dichotomy that previously existed in the literature between arc routing and node routing. In real applications, there are many cases where the pure node or arc routing models are not adequate. In fundamentally node-based routing applications such as newspaper delivery and communal waste management that have typically been modeled as arc routing problems in the literature, the number of points is often so large that demand aggregation is necessary. The first combinatorial lower bound was developed by Bach, Hasle, and Wøhlk [3]. They also developed two new benchmarks: BHW and DI-NEARP.

The Spider solver is integrated in the web-solution for management of carrier routes of the Norwegian company Distribution Innovation AS [1]. The DI solution is used by more than 35 distribution and newspaper companies in Norway, Sweden, and Finland. Through the web, the companies may create, optimize, and revise their carrier routes. Typically, a route planning session will comprise many hundreds or thousands of delivery addresses. Through demand aggregation heuristics, the basic node routing problem is transformed to a NEARP with substantially fewer demands.

There are two main objectives for the experimental study reported here:

- to perform a comparative investigation of the NEARP performance of Spider on the CBMix benchmark
- to provide the first upper bound for the novel BHW and DI-NEARP benchmarks

An experimental study with Spider on the NEARP benchmarks was conducted in 2011. Due to errors, we decided to rerun the experiments in May 2012. The current report contains the results of the May 2012 experiments.

2 Experimental setup

The three existing NEARP benchmarks from the literature were used:

1. CBMix: the 23 original benchmarks created by Prins and Bouchenoua [6]. These instances are all based on graphs with a grid structure.
2. BHW: A set of 20 instances generated by Bach, Hasle, and Wøhlk from popular benchmark instances for the CARP [3].
3. DI-NEARP: A set of 24 instances generated by Bach, Hasle, and Wøhlk from six real life cases from the design of carrier routes for home delivery of subscription newspapers. The six cases were taken from Distribution Innovation AS [1]. These instances only include nodes and edges, no arcs.

For details on the novel BHW and DI-NEARP benchmarks, we refer to [3].

All computational experiments were performed on a PC with an Intel Core i7 950, running at 3.07 GHz and with 12GB of RAM.

The algorithmic parameters to Spider were:
-CP -ins -rel -two 0 -cro 20 -ex -seg 3 -nex 12 0 0 0 0 -rar 10 4 3 3 -rou 0.7 0.1 -three 0

The main parameters have the following meaning. The Spider Constructor was used to create the initial solution. It is an extension of the well-known

Solomon I1 constructor for the VRPTW, both to accommodate the rich Spider model, and to perform a limited search over parameter values to get a better initial solution. The *insert*, *relocate*, *2-opt*, *3-opt*, *2-opt** (*cross*), and *cross-exchange* local search operators were used. They are all run to a local optimum. The *2-opt** operator tries to all segment lengths up to 20. The standard *cross-exchange* operator tries all segment lengths up to 3. In addition, a heuristic *cross-exchange* operator that tries to get rid of long arcs is employed, where a maximum number of 12 arcs are identified.

All cases were run both with diversification based on Spider's standard set of destroy and repair heuristics once the local search finds a local minimum, and also with a simpler diversification mechanism based on random removal, with 50% probability of using the current solution instead of the incumbent when diversifying. The best solution from the two runs was reported. The timeout was set to 7200 seconds (2 hours), but the actual CPU time for the best solution found was recorded.

3 Results

Tables 1, 2, and 3 show the results for the CBMix, BHW, and DI-NEARP instances, respectively. The column headings have the following meaning for CBmix:

- Instance: Instance name.
- U^S: The upper bound found by Spider
- U^*: Value of previously best known solution.
- G^B: The relative gap between U^S and U^*
- CPU: Spider's runtime to find the solution (in seconds).

The best known solutions were taken from [6], and [5]. The gap G^B has been calculated according to the following formula:

$$G^B = \frac{U^S - U^*}{(U^S + U^*)/2} 100$$

For the instances where Spider has found a new best or equally good solution, the values are marked in boldface.

For the novel BHW and DI-NEARP instances where Spider has produced the first upper bounds, the columns are as follows:

- Instance: Instance name.
- U^S: The upper bound found by Spider
- L^*: The best lower bound, taken from [3]
- G^O: The relative optimality gap
- CPU: Spider's runtime to find the solution (in seconds).

G^O has been calculated in a similar way as G^B. Optimal values are marked in boldface.

The CBMix benchmark. Table 1 shows that Spider has produced two new best solutions, and six solutions that are equally good as the competition. The relative gap to the previous best known solution varies between -0.5% and 3.0% with an average of 0.9%. The CPU times and gaps indicate that CBMix11, CBMix12, CBMix22, and CBMix23 are relatively easy instances.

The BHW benchmark. As can be observed from Table 2, Spider has found optimal solutions for BHW2, BHW4, and BHW6. There is no upper bound competition, but the relative optimality gaps vary between 0% and 55.4% with an average of 24.2%. It is difficult to know whether the large gaps are due to the upper bound or the lower bound. The runtimes and gaps indicate that BHW1-BHW2 and BHW4-BHW6 are easy instances. The result for BHW3 is interesting. The best solution is found after 18 seconds, and no better solution is found before the timeout at 7200 seconds. Still, the optimality gap is 24%. This indicates either a poor lower bound, or a missing diversification mechanism in Spider.

The DI-NEARP benchmark. Again, there is no upper bound competition. Table 3 shows that the relative optimality gaps vary between 7.0% and 54.8% with an average of 27.8%. It is difficult to know whether the large gaps are due to the quality of the upper or the lower bound, or both. A general trend that can be observed from the gaps is that the instances seem to get easier with increasing capacity, either for Spider, or for the lower bound procedure, or both.

Instance	U^S	U^*	G^B	CPU (s)
CBMix1	**2589**	2589	0.0	1231
CBMix2	12222	12220	0.0	4156
CBMix3	**3643**	3660	-0.5	6612
CBMix4	7802	7583	2.8	6744
CBMix5	**4531**	4531	0.0	1349
CBMix6	**7087**	7087	0.0	6687
CBMix7	**9607**	9615	-0.1	3205
CBMix8	10669	10524	1.4	1413
CBMix9	4130	4038	2.3	5517
CBMix10	7794	7582	2.8	4665
CBMix11	4525	4494	0.7	536
CBMix12	**3235**	3235	0.0	14
CBMix13	9135	9110	0.3	1427
CBMix14	8579	8566	0.2	6404
CBMix15	8371	8280	1.1	3553
CBMix16	9022	8886	1.5	6754
CBMix17	4097	4037	1.5	1271
CBMix18	7133	7098	0.5	1994
CBMix19	16692	16347	2.1	5688
CBMix20	4859	4844	0.3	3501
CBMix21	18809	18069	3.0	5322
CBMix22	**1941**	1941	0.0	492
CBMix23	**780**	780	0.0	0.3
Average			0.9	3415

Table 1: Spider results for the CBMix instances. Results equal to or better than the previous best known value are marked in boldface.

Instance	U^S	L^*	G^O	CPU (s)
BHW1	337	324	3.9	6
BHW2*	**470**	**470**	0.0	36
BHW3	415	326	24.0	18
BHW4*	**240**	**240**	0.0	1
BHW5	506	502	2.4	610
BHW6*	**388**	**388**	0.0	58
BHW7	1094	930	16.2	6324
BHW8	672	644	4.4	1801
BHW9	920	791	12.3	2431
BHW10	8596	6810	22.7	6205
BHW11	5023	3986	23.0	3012
BHW12	11042	6346	53.5	6059
BHW13	14510	8746	50.2	5723
BHW14	25194	17762	36.5	4584
BHW15	15509	12193	23.9	6728
BHW16	44527	26014	54.0	5747
BHW17	26768	15396	55.4	6823
BHW18	15833	11202	35.5	5532
BHW19	9480	7080	28.9	3605
BHW20	16625	10730	44.8	6769
Average			24.2	3604

Table 2: Spider results and lower bounds for the BHW instances. Instances that are closed are marked with *.

Instance	U^S	L^*	G^O	CPU (s)
DI-NEARP-n240-Q2k	24371	16376	39.2	4569
DI-NEARP-n240-Q4k	18352	14362	24.4	4495
DI-NEARP-n240-Q8k	15397	13442	17.0	6421
DI-NEARP-n240-Q16k	14953	13116	13.1	5274
DI-NEARP-n422-Q2k	18990	11623	48.1	6629
DI-NEARP-n422-Q4k	15987	11284	34.5	4524
DI-NEARP-n422-Q8k	14627	11220	26.4	2925
DI-NEARP-n422-Q16k	14357	11198	24.7	4661
DI-NEARP-n442-Q2k	51656	35068	38.3	7091
DI-NEARP-n442-Q4k	45605	33585	30.4	6308
DI-NEARP-n442-Q8k	44652	32985	30.1	5964
DI-NEARP-n442-Q16k	42797	32713	26.7	6480
DI-NEARP-n477-Q2k	23124	19722	15.9	5996
DI-NEARP-n477-Q4k	20198	18031	11.3	7006
DI-NEARP-n477-Q8k	18561	17193	7.7	2999
DI-NEARP-n477-Q16k	18105	16873	7.0	4079
DI-NEARP-n699-Q2k	59817	34101	54.8	6993
DI-NEARP-n699-Q4k	40473	26891	40.3	7178
DI-NEARP-n699-Q6k	30992	23302	28.3	6095
DI-NEARP-n699-Q8k	27028	21967	20.7	3173
DI-NEARP-n833-Q2k	56877	32435	54.7	7135
DI-NEARP-n833-Q4k	42407	29381	36.3	6861
DI-NEARP-n833-Q8k	35267	28453	21.4	6940
DI-NEARP-n833-Q16k	33013	28233	15.6	4046
Average			27.8	5577

Table 3: Results obtained for the DI-NEARP instances.

4 The NEARP web pages

NEARP subpages have been added to SINTEF's TOP website [2], with the shortcut address of `http://www.sintef.no/NEARP`. Here, you find the instance definitions of the CBMix, BHW, and DI-NEARP benchmarks in a standard format that is documented. Also, a detailed solution format is proposed. For all instances you find the best known upper bound, the best known lower bound, and the relative optimality gap, with reference to the publication. For most instances, the detailed solutions are accessible. It is our hope that we will be able to keep these pages updated with the best results from the literature. For this, we are totally dependent on the research community.

SINTEF has developed a NEARP solution checker. Authors are encouraged to send their new best known solutions in the detailed solution format. Likewise, we are depending on reports from authors for keeping the best known lower bounds updated. Also, we hope that new NEARP benchmarks will be forwarded to us. Information should be forwarded to SINTEF at `top-request@sintef.no`.

5 Summary and Conclusion

The Node, Edge, and Arc Routing Problem (NEARP), or the Mixed Capacitated General Routing Problem (MCGRP), is a scientifically very challenging problem with many real-life applications. This report gives results from running SINTEF's industrial solver Spider on the three known NEARP benchmarks. Spider has provided the first solutions to the new BHW and DI-NEARP benchmarks. Three of the BHW instances have been closed by Spider. For the CBMix benchmark, Spider has produced two new best solutions.

SINTEF has established a web site for NEARP. It is our hope that more research effort will be devoted to the NEARP to the future, and that the community will help us keeping the NEARP web site updated.

6 Acknowledgments

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