TABLE I: Results of benchmark instances for the traditional VRPB.

Instance	BCP$_{F2}$			CPLEX			LKH-3			GA			LNS			AM(Sampling)			POMO			Ours		
	Obj.	Gap	Time(s)	Obj.	Gap	Time(s)	Obj.	Gap	Time(s)	Obj.	Gap	Time(s)	Obj.	Gap	Time(s)	Obj.	Gap	Time(s)	Obj.	Gap	Time(s)	Obj.	Gap	Time(s)
X-n101-50-k13	18926	0.00%	73	—	—	—	—	—	—	59955	216.79%	56.316	34483	82.20%	1.394	55551	193.52%	250.656	26314	39.04%	4.672	24643	30.21%	6.031
X-n101-66-k17	20357	0.00%	162	22510	10.58%	3600	—	—	—	57028	180.14%	52.683	39903	96.02%	1.345	55834	174.27%	360.318	31183	53.18%	5.315	28943	42.18%	6.932
X-n101-80-k21	23305	0.00%	33	24745	6.18%	3600	—	—	—	61967	165.90%	58.929	39803	70.79%	1.267	56193	141.12%	552.040	33351	43.11%	9.261	32960	41.43%	12.118
X-n106-50-k7	15413	0.00%	20	—	—	—	15556	0.93%	3600	52256	239.04%	54.328	26962	74.93%	0.690	49309	219.92%	233.871	18596	20.65%	5.346	18437	19.62%	7.163
X-n106-66-k9	18984	0.00%	40	22821	20.21%	3600	19280	1.56%	3600	48535	155.66%	47.879	29562	55.72%	0.886	49021	158.22%	389.039	21947	15.61%	3.049	21697	14.29%	4.044
X-n106-80-k11	22099	0.00%	397	23241	5.17%	3600	22876	3.52%	3600	48744	120.57%	48.134	30331	37.25%	0.852	51367	132.44%	643.052	25804	16.77%	5.182	25183	13.96%	6.837
X-n110-50-k7	13103	0.00%	10	16431	25.40%	3600	13055	-0.37%	3600	38190	191.46%	58.281	23839	81.94%	1.385	58091	343.34%	259.981	16489	25.84%	1.403	15645	19.40%	1.894
X-n110-66-k9	13598	0.00%	9	14654	7.77%	3600	13981	2.82%	3600	36810	170.70%	53.542	23721	74.44%	0.966	58236	328.27%	441.259	17415	28.07%	2.832	16822	23.71%	3.736
X-n110-80-k11	14215	0.00%	281	16726	17.66%	3600	14887	4.73%	3600	41038	188.70%	50.484	20692	45.56%	1.953	58736	313.20%	676.249	19220	35.21%	5.123	17705	24.55%	6.757
X-n115-50-k8	13927	0.00%	722	14316	2.79%	3600	—	—	3600	36747	163.85%	52.258	31694	127.57%	1.761	59402	326.52%	315.185	20111	44.40%	2.268	19522	40.17%	2.311
X-n115-66-k8	14032	0.00%	725	15035	7.15%	3600	14960	6.61%	3600	40391	187.85%	48.814	24732	76.25%	1.217	59616	324.86%	464.385	19430	38.47%	3.656	19134	36.36%	4.856
X-n115-80-k9	13536	0.00%	31	16462	21.62%	3600	13759	1.65%	3600	39516	191.93%	49.389	23460	73.32%	1.060	59498	339.55%	853.424	19086	41.00%	5.692	18072	33.51%	5.799
X-n120-50-k3	12416	0.00%	73	20528	65.34%	3600	12376	-0.32%	3600	33399	169.00%	98.300	23100	86.05%	2.322	66498	435.58%	342.041	15465	24.56%	7.732	14774	18.99%	10.258
X-n120-66-k4	13145	0.00%	325	13629	3.68%	3600	13387	1.84%	3600	34602	163.23%	76.157	23555	79.19%	2.015	65900	401.33%	554.651	14823	12.77%	1.326	15422	17.32%	1.830
X-n120-80-k5	13465	0.00%	2737	14966	11.15%	3600	13626	1.20%	3600	36920	174.19%	77.222	23419	73.92%	1.215	65811	388.76%	293.551	16301	21.06%	2.500	16761	24.48%	3.172
X-n125-50-k16	32065	0.00%	915	—	—	—	—	—	—	92346	188.00%	65.038	50970	58.96%	1.304	72566	126.31%	374.119	39957	24.61%	8.960	38129	18.91%	11.122
X-n125-66-k19	36349	0.00%	271	—	—	—	—	—	—	96233	164.75%	63.552	56028	54.14%	1.147	74031	103.67%	647.155	44864	23.43%	9.384	45821	26.06%	11.731
X-n125-80-k23	43823	0.00%	11877	61525	40.39%	3600	—	—	—	102387	133.64%	73.035	58710	33.97%	1.443	76820	75.30%	1005.608	54652	24.71%	16.339	54463	24.28%	22.023
X-n129-50-k10	19409	0.00%	335	59118	204.59%	3600	21059	8.50%	3600	59352	205.80%	69.256	35588	83.36%	1.105	69086	255.95%	365.167	25290	30.30%	2.731	23979	23.55%	3.836
X-n129-66-k12	22554	0.00%	226	30957	37.26%	3600	—	—	—	62263	176.06%	59.716	38277	69.71%	0.917	70438	212.31%	659.837	29165	29.31%	5.985	28457	26.17%	7.948
X-n129-80-k14	24553	0.00%	108	34742	41.50%	3600	—	—	—	65494	166.75%	61.819	38471	56.69%	0.815	71857	192.66%	984.720	32349	31.75%	10.045	31336	27.63%	11.833
X-n134-50-k7	8316	0.00%	868	—	—	—	8562	2.96%	—	34669	316.90%	77.884	16765	101.60%	1.266	39823	378.87%	412.911	11698	40.67%	11.040	10571	27.12%	14.292
X-n134-66-k9	8891	0.00%	621	10466	17.71%	3600	9316	4.78%	3600	28587	221.53%	70.026	15526	74.63%	1.043	39094	339.70%	548.683	12336	38.75%	4.149	11968	34.61%	5.546
X-n134-80-k11	9637	0.00%	1222	13234	37.32%	3600	—	—	3600	28849	199.36%	64.590	16043	66.47%	1.374	40303	318.21%	870.209	14348	48.88%	7.593	13626	41.39%	9.902
X-n139-50-k5	13237	0.00%	290	—	—	—	13319	0.62%	—	43201	226.37%	65.640	23907	80.61%	2.461	71498	440.14%	452.822	16386	23.79%	12.057	15663	18.33%	15.408
X-n139-66-k7	13512	0.00%	51	14510	7.39%	3600	13761	1.84%	3600	42321	213.21%	75.953	24121	78.52%	0.863	72185	434.23%	858.646	16881	24.93%	3.473	16649	23.22%	4.494
X-n139-80-k8	13662	0.00%	40	16401	20.05%	3600	14996	9.76%	3600	45842	235.54%	67.084	23305	70.58%	1.013	72830	433.08%	1228.662	17855	30.69%	6.582	18097	32.46%	8.525
X-n143-50-k4	24553	0.00%	214	—	—	—	14476	-0.43%	3600	55146	279.30%	118.462	29247	101.16%	1.265	84207	479.18%	502.804	20280	39.49%	13.095	18751	28.97%	17.356
X-n143-66-k4	14310	0.00%	82	19055	33.16%	3600	14253	-0.40%	3600	47991	235.37%	122.77	25775	80.12%	1.589	82738	478.18%	920.191	19084	33.36%	1.882	18692	30.62%	2.493
X-n143-80-k5	14397	0.00%	2822	17565	22.00%	3600	14511	0.79%	3600	42456	194.89%	92.877	29457	104.61%	1.221	82231	471.17%	314.066	20174	40.13%	3.428	19647	36.47%	4.574
X-n148-50-k25	28210	0.00%	30	—	—	—	—	—	—	59726	111.72%	444.797	51667	83.15%	1.897	79651	182.35%	536.374	36186	28.27%	14.737	33998	20.52%	18.494
X-n148-66-k29	30392	0.00%	112	—	—	—	—	—	—	68182	124.34%	204.744	54634	79.76%	1.167	80006	163.25%	979.871	45176	48.64%	21.538	43081	41.75%	23.296
X-n148-80-k36	35333	0.00%	318	59116	67.31%	3600	—	—	3600	87536	147.75%	102.427	62426	76.68%	1.387	80494	127.82%	1429.336	50637	43.31%	38.026	47899	35.56%	37.690

Instance	BCP_{F2} Obj.	Gap	Time(s)	CPLEX Obj.	Gap	Time(s)	LKH-3 Obj.	Gap	Time(s)	GA Obj.	Gap	Time(s)	LNS Obj.	Gap	Time(s)	AM(Sampling) Obj.	Gap	Time(s)	POMO Obj.	Gap	Time(s)	Ours Obj.	Gap	Time(s)
X-n153-50-k19	20536	0.00%	23	22401	9.08%	3600	—	—	—	54341	164.61%	83.752	40690	98.14%	1.691	68465	233.39%	576.285	28157	37.11%	9.713	27402	33.43%	10.022
X-n153-66-k20	20613	0.00%	31	27258	32.24%	3600	—	—	—	52977	157.01%	96.038	40206	95.05%	1.217	69283	236.11%	1052.979	30293	46.96%	17.155	27850	35.11%	17.761
X-n153-80-k21	20811	0.00%	57	24422	17.35%	3600	—	—	—	49269	136.74%	101.853	37840	81.83%	1.077	70831	240.35%	1551.680	28853	38.64%	24.266	28704	37.93%	25.147
X-n157-50-k7	11727	0.00%	37	49641	323.31%	3600	19865	69.40%	3600	42728	264.36%	79.927	21741	85.39%	0.862	71833	512.54%	577.031	14793	26.14%	17.709	14567	24.22%	18.153
X-n157-66-k9	13651	0.00%	43	18108	32.65%	3600	35820	162.40%	3600	40484	196.56%	86.923	24449	79.10%	0.910	72091	428.10%	674.011	17898	31.11%	5.599	16543	21.19%	5.912
X-n157-80-k11	15246	0.00%	733	17706	16.14%	3600	23737	55.69%	3600	42882	181.27%	80.866	23711	55.52%	0.817	73576	382.59%	929.516	20272	32.97%	10.012	18114	18.81%	10.694
X-n162-50-k6	12812	0.00%	157	21564	68.31%	3600	12768	-0.34%	3600	55695	334.71%	102.215	23467	83.16%	0.996	78950	516.22%	649.020	16299	27.22%	2.339	15977	24.70%	2.552
X-n162-66-k8	13301	0.00%	19365	14445	8.60%	3600	13592	2.19%	3600	44337	233.34%	97.671	22476	68.98%	1.046	79341	496.50%	560.246	17567	32.07%	5.246	17322	30.23%	5.477
X-n162-80-k9	13854	0.00%	812	19422	40.19%	3600	14358	3.64%	3600	45181	226.12%	83.875	19690	42.13%	1.099	80268	479.39%	814.259	17755	28.16%	8.650	18445	33.14%	9.027
X-n167-50-k5	16489	0.00%	336	31400	90.43%	3600	16627	0.84%	3600	52388	217.71%	110.357	37900	129.85%	1.248	93321	465.96%	618.061	20283	23.01%	20.684	19493	18.22%	21.527
X-n167-66-k7	17717	0.00%	3411	27038	52.61%	3600	19073	7.65%	3600	55083	210.90%	107.633	37187	109.89%	1.334	92146	420.10%	506.907	22266	25.68%	4.779	22737	28.33%	5.173
X-n167-80-k8	19383	0.00%	770	28120	45.08%	3600	20496	5.74%	3600	60899	214.19%	86.643	31173	60.83%	1.130	92329	376.34%	728.469	25393	31.01%	8.070	25767	32.94%	8.464
X-n172-50-k27	30535	0.00%	270	—	—	—	—	—	—	104187	241.21%	113.297	46702	52.95%	1.072	91879	200.90%	744.508	45085	47.65%	24.248	38132	24.88%	24.791
X-n172-66-k31	31808	0.00%	161	—	—	—	—	—	—	105375	231.28%	110.495	51829	62.94%	1.495	93878	195.14%	1314.079	48760	53.29%	28.363	42280	32.92%	30.487
X-n172-80-k39	36746	0.00%	560	42044	14.42%	3600	—	—	—	100874	174.52%	119.097	58266	58.56%	1.736	94435	156.99%	1931.767	58118	58.16%	55.550	48864	32.98%	59.308
X-n176-50-k23	45162	0.00%	437	52931	17.20%	3600	—	—	—	102595	127.17%	138.543	79078	75.10%	1.634	106279	135.33%	767.261	61520	36.22%	14.480	58223	28.92%	15.789
X-n176-66-k24	46337	0.00%	736	54648	17.94%	3600	—	—	—	117739	154.09%	119.553	81678	76.27%	2.089	108404	133.95%	1408.821	62776	35.48%	25.046	61080	31.82%	26.629
X-n176-80-k25	46987	0.00%	341	60342	28.42%	3600	—	—	—	119081	153.43%	121.452	85886	82.79%	1.526	111557	137.42%	2168.249	63174	34.45%	39.620	63985	36.18%	37.748
X-n181-50-k12	16549	0.00%	57	51216	209.48%	3600	—	—	—	49103	196.71%	126.011	28457	71.96%	1.369	72613	338.78%	806.799	19789	19.58%	30.610	19238	16.25%	27.536
X-n181-66-k15	18832	0.00%	41	25241	34.03%	3600	—	—	—	60347	220.45%	88.974	30051	59.57%	1.047	73492	290.25%	1370.402	23466	24.61%	14.418	23265	23.54%	13.718
X-n181-80-k18	21241	0.00%	54	27979	31.72%	3600	—	—	—	62524	194.36%	88.743	29154	37.25%	1.092	74703	251.69%	2097.379	26747	25.92%	24.515	26193	23.31%	24.304
X-n186-50-k8	17868	0.00%	9088	—	—	—	18585	61.71%	3600	80710	351.70%	112.233	37800	111.55%	1.271	107311	500.58%	881.772	21361	19.55%	30.952	21858	22.33%	31.025
X-n186-66-k10	19751	0.00%	302	28957	46.61%	3600	20058	57.70%	3600	66044	234.38%	106.510	33453	69.37%	1.169	106689	440.17%	863.495	25908	31.17%	9.428	25421	28.71%	9.390
X-n186-80-k12	21631	0.00%	21953	35476	64.01%	3600	28186	96.56%	3600	69555	221.55%	83.939	34811	60.93%	1.242	107210	395.63%	1305.127	29834	37.92%	16.526	29459	36.19%	16.116
X-n190-50-k4	11493	0.00%	9096	—	—	—	—	—	—	33120	188.18%	234.053	21998	91.40%	2.999	65007	465.62%	892.589	16462	43.24%	32.987	14693	27.84%	32.580
X-n190-66-k5	12719	0.00%	—	18749	47.41%	3600	—	—	—	27969	119.90%	208.807	22741	78.80%	2.253	62983	395.19%	1619.939	15676	23.25%	4.573	15987	25.69%	4.360
X-n190-80-k6	14340	0.00%	—	20705	44.39%	3600	—	—	—	36208	152.50%	151.281	23711	65.35%	1.945	62827	338.12%	538.239	17938	25.09%	8.156	18334	27.85%	7.760
X-n195-50-k27	29376	0.00%	698	—	—	—	—	—	—	109849	273.94%	132.348	55657	89.46%	1.920	99583	238.99%	920.564	41744	42.10%	20.555	41038	39.70%	20.019
X-n195-66-k34	33077	0.00%	166	—	—	—	—	—	—	103113	211.74%	127.015	65806	98.95%	1.588	101918	208.12%	1617.328	48609	46.96%	46.284	47142	42.52%	44.090
X-n195-80-k42	38629	0.00%	186	—	—	—	—	—	—	103407	167.69%	139.290	65877	70.54%	1.814	102556	165.49%	2634.872	53752	39.15%	83.972	53308	38.00%	84.101
X-n200-50-k18	34291	0.00%	81125	—	—	—	—	—	—	138817	304.82%	87.275	57922	68.91%	1.340	107349	213.05%	1050.741	42995	25.38%	39.215	42510	23.97%	38.717
X-n200-66-k24	40321	0.00%	—	72616	80.09%	3600	—	—	—	115429	186.28%	142.721	58133	44.18%	1.067	111606	176.79%	1862.389	53994	33.91%	30.964	49464	22.68%	30.222
X-n200-80-k29	47714	0.00%	585	—	—	—	—	—	—	131462	175.52%	73.864	66399	39.16%	1.267	115814	142.73%	2689.703	59827	25.39%	55.331	56525	18.47%	54.081

TABLE II: Results of benchmark instances for the improved VRPB.

Instance	$\mathcal{V}$	RTS			Halse			POMO			Ours		
		Obj.	Gap	Time(s)	Obj.	Gap	Time(s)	Obj.	Gap	Time(s)	Obj.	Gap	Time(s)
A1	25	223088	0.00%	0.12	227725	2.08%	0.18	252586	13.22%	0.074	**218636**	**-2.00%**	**0.141**
A2	25	169450	0.00%	1.1	**169497**	**0.03%**	**0.09**	200788	18.49%	0.074	187178	10.46%	0.139
A3	25	141984	0.00%	2.7	**142032**	**0.03%**	**0.05**	169015	19.04%	0.066	157633	11.02%	0.144
B1	30	232371	0.00%	0.14	233950	0.68%	0.13	228069	-1.85%	0.067	**178701**	**-23.10%**	**0.150**
B2	30	179194	0.00%	0.11	182326	1.75%	0.07	169766	-5.26%	0.068	**154835**	**-13.59%**	**0.146**
B3	30	145583	0.00%	0.27	145699	0.08%	0.3	135569	-6.88%	0.072	**134622**	**-7.53%**	**0.150**
C1	40	237100	0.00%	1.02	242931	2.46%	0.69	200847	-15.29%	0.156	**179478**	**-24.30%**	**0.207**
C2	40	196683	0.00%	0.11	197276	0.30%	0.74	190641	-3.07%	0.132	**166557**	**-15.32%**	**0.198**
C3	40	164794	0.00%	3.42	167663	1.74%	0.06	190641	15.68%	0.133	**165184**	**0.24%**	**0.215**
D1	38	307109	0.00%	2.63	307875	0.25%	0.47	379438	23.55%	0.081	**302853**	**-1.39%**	**0.156**
D3	38	220700	0.00%	2.34	**222195**	**0.68%**	**0.18**	282539	28.02%	0.082	251700	14.05%	0.152
E1	45	220742	0.00%	0.11	**222518**	**0.80%**	**0.43**	258360	17.04%	0.089	245284	11.12%	0.176
E2	45	190601	0.00%	0.16	**190048**	**-0.29%**	**0.07**	232747	22.11%	0.085	221163	16.03%	0.150
E3	45	183237	0.00%	13.98	**187793**	**2.49%**	**0.16**	222475	21.41%	0.088	220329	20.24%	0.160
F1	60	249335	0.00%	7.18	254977	2.26%	0.53	204355	-18.04%	0.182	**194697**	**-21.91%**	**0.246**
F3	60	221667	0.00%	0.15	215575	-2.75%	0.44	203243	-8.31%	0.184	**206050**	**-7.05%**	**0.253**
F4	60	204397	0.00%	3.42	203448	-0.46%	0.41	210782	3.12%	0.170	**203166**	**-0.60%**	**0.249**
G1	57	297707	0.00%	5.29	**304106**	**2.15%**	**0.41**	446864	50.10%	0.101	386646	29.87%	0.187
G2	57	234896	0.00%	0.32	**235220**	**0.14%**	**0.17**	370367	57.67%	0.108	330860	40.85%	0.193
G3	57	215324	0.00%	2.14	**213757**	**-0.73%**	**0.22**	322651	49.84%	0.094	310617	44.26%	0.178
G5	57	202733	0.00%	0.35	**202610**	**-0.06%**	**0.33**	286276	41.21%	0.104	272986	34.65%	0.169
G6	57	189166	0.00%	1.22	**201875**	**6.72%**	**0.33**	276748	46.30%	0.102	250397	32.37%	0.178
H1	68	236362	0.00%	15.64	**235269**	**-0.46%**	**0.65**	289287	22.39%	0.116	253455	7.23%	0.219
H2	68	214908	0.00%	3.12	**215649**	**0.34%**	**0.18**	245876	14.41%	0.108	225150	4.77%	0.188
H3	68	205726	0.00%	0.75	**202971**	**-1.34%**	**0.12**	253614	23.28%	0.112	219244	6.57%	0.184
H5	68	203051	0.00%	0.84	**201896**	**-0.57%**	**0.24**	231091	13.81%	0.119	209112	2.98%	0.199
I1	90	320703	0.00%	1.55	329237	2.66%	1.06	246240	-23.22%	0.283	**224927**	**-29.86%**	**0.358**
I2	90	274657	0.00%	32.49	289501	5.40%	1.76	242779	-11.61%	0.274	**224008**	**-18.44%**	**0.338**
I3	90	239292	0.00%	3.72	244782	2.29%	3.83	239384	0.04%	0.294	**237696**	**-0.67%**	**0.355**
J1	94	330501	0.00%	1.32	**337800**	**2.21%**	**1.08**	501321	51.69%	0.161	427929	29.48%	0.243
J2	94	294446	0.00%	1.48	**298432**	**1.35%**	**1.32**	439732	49.34%	0.171	421325	43.09%	0.242
J3	94	249931	0.00%	7.31	**280070**	**12.06%**	**0.38**	405059	62.07%	0.158	369063	47.67%	0.239
J4	94	275344	0.00%	1.66	**257895**	**-6.34%**	**0.53**	418896	52.14%	0.162	385786	40.11%	0.251
K1	113	352253	0.00%	10.33	**361287**	**2.56%**	**1.4**	464518	31.87%	0.187	441351	25.29%	0.272
K2	113	317004	0.00%	35.42	**320012**	**0.95%**	**1.57**	430995	35.96%	0.187	408675	28.92%	0.273
K4	113	295259	0.00%	10.48	**296766**	**0.51%**	**0.66**	433567	46.84%	0.187	402151	36.20%	0.263
L1	150	394414	0.00%	20.68	412278	4.53%	3.81	323665	-17.94%	0.532	**334269**	**-15.25%**	**0.620**
L2	150	365983	0.00%	13.33	362399	-0.98%	4.01	318419	-13.00%	0.575	**317090**	**-13.36%**	**0.622**
L4	150	341887	0.00%	77.27	341304	-0.17%	2.09	319162	-6.65%	0.528	**313673**	**-8.25%**	**0.610**
M1	125	360897	0.00%	17.63	**372840**	**3.31%**	**2.41**	605827	67.87%	0.238	525855	45.71%	0.310
M3	125	340362	0.00%	10.99	**336011**	**-1.28%**	**2.71**	559128	64.27%	0.226	475536	39.71%	0.324
M4	125	304680	0.00%	78.77	**305118**	**0.14%**	**0.82**	488195	60.23%	0.230	464369	52.41%	0.315
N1	150	375576	0.00%	17.32	**385978**	**2.77%**	**2.60**	612798	63.16%	0.292	513367	36.69%	0.373
N3	150	354526	0.00%	22.82	**352992**	**-0.43%**	**2.82**	575237	62.26%	0.287	515417	45.38%	0.377
N5	150	327174	0.00%	133.62	**319811**	**-2.25%**	**3.11**	550026	68.11%	0.281	475656	45.38%	0.374