Supplementary material for the paper: Intermodal hub network design with probabilistic service level constraints

Detailed results

This document reports supplementary results for the paper entitled *Intermodal hub network design with probabilistic service level constraints* by M.J. Basallo-Triana, J.F. Cordeau, and N. Vidyarthi.

Tables 1 and 2 show the detailed results for the exact formulations $M1$ and $M3$. The first column is the instance descriptor. The second column refers to the value of parameter r. The objective function value is shown in the third column. The columns under the heading *Time* report the solution time in seconds. The columns under the heading *Opt. Gap. (%)* show the optimality gap. The column labeled *hubs* shows the optimal hubs. Note that a solution with no hubs is possible. The column labeled *Min S.L. (%)* reports the minimum network service level. Finally, the column labeled *Connectivity (%)* refers to the percentage of inter-hub arcs that are activated in an optimal solution with respect to the total number of hub arcs that can be activated according to the open hubs.

Table 1: Detailed results for formulations $M1$ and $M3$ for the AP data set.

Instance	r	100α	Obj. Val.	Time (sec)		B&B nodes		Opt. Gap. (%)		Hubs	Min S.L. (%)	Connectivity (%)
				$M1$	$M2$	$M1$	$M2$	$M1$	$M2$			
10ll	2	80	292,698	0.1	0.2	0	5			4 5 6 7 8	80.064	90
10ll	2	85	328,484	0.1	0.2	6	5			4 5 6 7	85	66
10ll	2	90	360,112	0.1	0.1	15	18			5 6 7 8	90	33
10ll	2	95	369,919	0.0	0.0	0	0					
10ll	2	99	369,919	0.0	0.0	0	0					
10lt	2	80	308,760	0.0	0.0	0	0			1 4 5 6	80	100
10lt	2	85	328,271	0.1	0.1	6	3			1 4 5 6	85.329	50
10lt	2	90	369,919	0.0	0.0	0	1					
10lt	2	95	369,919	0.0	0.0	0	0					
10lt	2	99	369,919	0.0	0.0	0	0					
10tl	2	80	322,671	0.1	0.2	13	9			3 4 5 6	80.088	50
10tl	2	85	341,037	0.1	0.1	2	1			4 6	85.148	100
10tl	2	90	369,386	0.0	0.0	0	0			2 4	91.009	100
10tl	2	95	369,919	0.0	0.0	0	0					
10tl	2	99	369,919	0.0	0.0	0	0					
10tt	2	80	315,629	0.0	0.1	0	1			1 4 5 6	80	100
10tt	2	85	335,140	0.1	0.1	4	4			1 4 5 6	85.329	50
10tt	2	90	369,919	0.0	0.0	0	0					
10tt	2	95	369,919	0.0	0.0	0	0					
10tt	2	99	369,919	0.0	0.0	0	0					
20ll	2	80	304,596	15.5	15.3	134	166			7 10 14 15	80	100
20ll	2	85	321,015	16.4	13.9	134	120			6 7 10 14 15	85	90
20ll	2	90	355,504	3.1	2.9	13	13			6 7 10	90	100
20ll	2	95	405,379	0.0	0.0	0	0					
20ll	2	99	405,379	0.0	0.0	0	0					
20lt	2	80	313,409	26.8	28.7	447	383			6 10 14 19	80	100
20lt	2	85	327,513	13.6	4.6	249	99			6 10 14 19	85	100
20lt	2	90	371,606	2.3	3.4	75	78			6 10 14	90.085	100
20lt	2	95	405,379	0.0	0.0	0	0					
20lt	2	99	405,379	0.0	0.0	0	0					
20tl	2	80	323,987	17.9	13.2	131	117			7 10	80.071	100
20tl	2	85	336,789	5.1	6.7	19	25			7 10	85.27	100
20tl	2	90	364,915	2.2	1.1	9	9			7 10	90.104	100
20tl	2	95	405,379	0.0	0.0	0	0					
20tl	2	99	405,379	0.0	0.0	0	0					

Table 1 continued from previous page

Instance	r	100α	Obj. Val.	Time (sec)		B&B nodes		Opt. Gap. (%)		Hubs	Min S.L. (%)	Connectivity (%)
				$M1$	$M2$	$M1$	$M2$	$M1$	$M2$			
20tt	2	80	340,638	9.7	6.6	69	32			6 10	81.774	100
20tt	2	85	354,448	3.5	4.1	68	65			5 6 9 10	85	100
20tt	2	90	381,108	1.2	1.0	16	6			6 10	90.052	100
20tt	2	95	405,379	0.0	0.0	0	0					
20tt	2	99	405,379	0.0	0.0	0	0					
25ll	2	80	309,250	696.9	362.6	2,366	552			7 8 18 19	80	83
25ll	2	85	339,856	263.3	165.5	1,245	514			7 8 18 19	85	83
25ll	2	90	369,248	15.7	22.9	113	124			7 8 9 14	90	83
25ll	2	95	408,177	0.0	0.0	0	0					
25ll	2	99	408,177	0.0	0.0	0	0					
25lt	2	80	323,283	8,059.3	632.3	26,205	2,280			6 9 12 13 14 19	80	100
25lt	2	85	343,174	564.5	122.9	3,481	805			6 9 10 12 14	85	100
25lt	2	90	372,313	56.6	34.6	859	484			8 9 13 14	90	100
25lt	2	95	408,177	0.0	0.0	0	0					
25lt	2	99	408,177	0.0	0.0	0	0					
25tl	2	80	354,589	161.3	71.6	232	67			9 14	80.109	100
25tl	2	85	370,374	48.1	43.0	150	67			9 14	85.088	100
25tl	2	90	392,060	0.8	1.7	0	0			9 14	90.171	100
25tl	2	95	408,177	0.0	0.0	0	0					
25tl	2	99	408,177	0.0	0.0	0	0					
25tt	2	80	349,736	813.4	97.7	2,053	115			9 13 14	80	100
25tt	2	85	364,659	49.3	41.4	344	79			9 10 14	85.08	100
25tt	2	90	390,248	6.5	6.4	99	27			9 14	90.008	100
25tt	2	95	408,177	0.0	0.0	0	0					
25tt	2	99	408,177	0.0	0.0	0	0					
40ll	2	80	300,644	Time	15,090.3	6,089	453	0.341		14 15 29 30	80	100
40ll	2	85	316,593	18,812.9	17,169.9	2,643	1,134			14 15 29 30	85	100
40ll	2	90	348,352	10,996.5	581.1	2,448	120			29 30	90.011	100
40ll	2	95	401,760	2.7	4.3	2	14			29 30	95.022	100
40ll	2	99	418,755	2.8	0.0	0	0					
40lt	2	80	Time			8,110	3,076	13.344	4.154			
40lt	2	85	355,383	Time	65,512.4	14,000	10,140	9.096		12 14 19 29 30	85	90
40lt	2	90	384,232	75,922.3	2,968.4	53,921	2,213			13 14 29 30	90	83
40lt	2	95	418,755	2.8	3.6	0	0					
40lt	2	99	418,755	2.8	0.0	0	0					
40tl	2	80	361,458	74,035.1	8,078.1	3,922	248			14 19 21	80	100

Table 1 continued from previous page

Instance	r	100α	Obj. Val.	Time (sec)		B&B nodes		Opt. Gap. (%)		Hubs	Min S.L. (%)	Connectivity (%)
				$M1$	$M2$	$M1$	$M2$	$M1$	$M2$			
40tl	2	85	375,004	1,641.1	2,982.5	290	396			14 19 21	85	100
40tl	2	90	402,629	930.4	335.2	217	87			14 21	90.026	100
40tl	2	95	418,755	2.8	0.2	0	0					
40tl	2	99	418,755	2.8	0.0	0	0					
40tt	2	80	378,033	Time	3,514.1	10,186	217	1.483		6 14	80.117	100
40tt	2	85	392,933	29,079.8	1,007.9	6,717	91			6 14	85.649	100
40tt	2	90	409,586	284.1	140.8	229	33			6 14	90.1	100
40tt	2	95	418,755	2.8	0.2	0	0					
40tt	2	99	418,755	2.8	0.0	0	0					
10ll	3	80	191,015	0.4	0.5	13	41			1 2 4 5 6 7 8 9	81.831	100
10ll	3	85	194,990	0.3	0.3	4	2			1 2 4 5 6 7 8 9	85	100
10ll	3	90	212,523	0.7	0.6	32	52			1 2 4 5 7 8	90	100
10ll	3	95	258,080	0.1	0.1	0	0			2 5 6 7 8	95.091	100
10ll	3	99	341,496	0.1	0.1	8	0			4 5 6 7	99.127	50
10lt	3	80	223,550	0.4	0.6	2	4			1 2 4 5 6 9 10	80.482	100
10lt	3	85	242,721	1.2	1.6	47	188			1 2 4 5 6 9 10	85	100
10lt	3	90	247,319	0.5	0.5	4	10			1 2 4 5 6 9 10	90.318	100
10lt	3	95	274,520	0.5	0.5	27	27			1 4 5 6 9 10	95.051	100
10lt	3	99	352,244	0.0	0.0	0	0			2 4 6	99.058	66
10tl	3	80	241,911	0.9	0.8	91	77			1 2 4 5 8 10	82.017	100
10tl	3	85	248,076	1.1	1.1	65	92			3 4 5 6 8	85	100
10tl	3	90	258,060	0.5	0.8	30	130			1 2 4 5 6 9 10	90.595	100
10tl	3	95	290,801	0.3	0.5	17	24			4 5 6 8	95	100
10tl	3	99	355,780	0.0	0.0	0	2			2 4 6	99.023	66
10tt	3	80	238,040	0.5	0.5	3	6			1 2 4 5 6 9 10	80.482	100
10tt	3	85	257,211	0.6	0.8	24	39			1 2 4 5 6 9 10	85	100
10tt	3	90	261,809	0.3	0.5	8	7			1 2 4 5 6 9 10	90.318	100
10tt	3	95	286,789	0.4	0.6	7	13			1 4 5 6 9 10	95.051	100
10tt	3	99	356,542	0.1	0.0	0	0			2 4 6	99.058	66
20ll	3	80	234,574	184.8	236.0	503	452			6 7 14 15	80	100
20ll	3	85	240,774	93.7	113.9	384	233			6 7 14 15	85	100
20ll	3	90	253,894	121.8	157.5	604	850			6 7 9 14 15	90	100
20ll	3	95	279,195	57.9	65.6	385	360			6 7 14 15	95	100
20ll	3	99	344,306	9.8	10.9	134	302			6 7 10	99	100
20lt	3	80	245,090	496.1	406.3	3,560	1,171			2 6 10 12 13 14	80	100
20lt	3	85	254,041	620.0	302.2	6,851	1,589			2 6 8 9 10 14	85	100

Table 1 continued from previous page

Instance	r	100α	Obj. Val.	Time (sec)		B&B nodes		Opt. Gap. (%)		Hubs	Min S.L. (%)	Connectivity (%)
				$M1$	$M2$	$M1$	$M2$	$M1$	$M2$			
20lt	3	90	269,284	628.2	329.1	7,905	2,268			5 6 10 12 13 14 16	90	100
20lt	3	95	287,498	132.4	64.7	1,526	506			6 10 14 19	95	100
20lt	3	99	357,524	5.5	12.8	101	614			6 10	99.022	100
20tl	3	80	263,164	161.3	131.6	249	58			7 10 11	80	100
20tl	3	85	276,238	278.3	189.1	796	364			7 10 11	85	100
20tl	3	90	285,461	116.8	150.6	257	238			7 10 11	90	100
20tl	3	95	299,418	66.3	45.4	63	221			7 10	95.075	100
20tl	3	99	355,167	5.9	4.9	80	55			7 10	99.035	100
20tt	3	80	284,002	414.8	157.7	1,518	267			5 6 8 10	80	100
20tt	3	85	295,134	266.7	238.3	2,400	596			5 6 8 10	85	100
20tt	3	90	304,965	108.7	80.1	783	261			5 6 8 10 12	90	100
20tt	3	95	326,025	45.4	44.6	411	283			6 8 10	95	100
20tt	3	99	368,200	0.7	0.9	0	4			6 10	99.026	100
25ll	3	80	241,685	3,599.7	2,769.9	3,889	796			7 8 14 17 18	80	100
25ll	3	85	248,469	3,211.9	2,071.5	3,235	800			7 8 14 17 18 19	85	93
25ll	3	90	261,017	1,899.0	1,728.8	2,828	2,690			7 8 14 17 19	90	100
25ll	3	95	278,837	352.5	706.4	834	1,137			7 8 14 18 19	95	90
25ll	3	99	357,492	56.4	65.2	402	377			7 8 18 19	99	83
25lt	3	80	260,424	46,757.2	16,519.4	37,161	5,912			6 9 12 14 19	80	100
25lt	3	85	266,443	30,261.0	7,184.6	30,054	2,330			6 9 12 14 19	85	100
25lt	3	90	279,310	63,008.6	13,326.7	97,388	13,035			9 12 14 16 19	90	100
25lt	3	95	297,273	7,447.6	2,201.0	11,608	4,027			9 12 13 14 19	95	100
25lt	3	99	357,042	71.9	94.5	1,090	1,427			9 13 14 19	99	100
25tl	3	80	294,225	5,243.6	1,998.5	1,532	126			9 14	80.178	100
25tl	3	85	302,545	5,322.2	968.7	1,447	97			9 14	85.044	100
25tl	3	90	314,107	1,984.1	434.4	738	75			9 14	90.434	100
25tl	3	95	331,440	153.5	173.3	132	88			9 14	95.11	100
25tl	3	99	387,006	6.4	15.3	17	15			9 14	99.011	100
25tt	3	80	303,128	Time	2,001.1	63,836	1,090	0.334		9 12 13 14	80	100
25tt	3	85	310,246	38,377.6	2,779.7	43,237	1,693			9 13 14	85	100
25tt	3	90	318,161	17,488.7	864.5	14,596	530			9 13 14	90	100
25tt	3	95	330,984	1,957.6	400.2	3,064	589			9 13 14	95	100
25tt	3	99	382,509	15.5	23.5	165	159			9 14	99.006	100
40ll	3	80	Time			2,237	279	2.884	3.542			
40ll	3	85	Time			1,342	583	4.119	0.292			
40ll	3	90	258,333	Time	62,654.6	2,092	1,442	2.030		6 14 29 30	90	100

Table 1 continued from previous page

Instance	r	100α	Obj. Val.	Time (sec)		B&B nodes		Opt. Gap. (%)		Hubs	Min S.L. (%)	Connectivity (%)
				$M1$	$M2$	$M1$	$M2$	$M1$	$M2$			
40ll	3	95	295,110	Time	68,161.9	3,720	6,386	4.107		7 14 19 29 30	95	100
40ll	3	99	333,566	5,039.6	62,977.0	1,255	16,071			14 15 29 30	99	100
40lt	3	80	Time			1,547	428	12.562	7.566			
40lt	3	85	Time			1,382	529	14.640	5.742			
40lt	3	90	Time			3,256	900	15.822	6.134			
40lt	3	95	Time			3,306	1,370	12.362	4.979			
40lt	3	99	Time			42,303	89,672	2.909	0.573			
40tl	3	80	286,829	Time	27,989.6	440	182	4.174		14 19 21	80	100
40tl	3	85	308,607	Time	24,110.2	957	73	4.120		6 14 19 21	85	100
40tl	3	90	319,293	83,405.4	20,748.7	1,807	159			14 19 21	90.029	100
40tl	3	95	333,001	Time	6,468.6	879	318	3.884		14 19 21	95	100
40tl	3	99	393,704	1,170.3	1,174.5	331	512			14 21	99	100
40tt	3	80	328,108	Time	18,030.6	1,336	318	6.354		6 14 19	80	100
40tt	3	85	335,315	Time	18,054.0	1,610	860	7.350		6 14 19	85	100
40tt	3	90	338,907	Time	24,341.6	2,400	818	8.279		6 14 19	90	100
40tt	3	95	359,541	Time	7,958.0	4,055	168	7.665		14 19	95.031	100
40tt	3	99	405,365	2,372.1	881.0	1,244	500			6 14	99.003	100
10ll	4	80	179,418	0.4	0.9	58	54			1 2 3 5 6 7 8 10	80	100
10ll	4	85	181,579	0.4	0.4	14	6			1 2 3 4 5 7 9 10	86.686	96
10ll	4	90	183,484	0.1	0.2	1	7			1 2 3 4 5 7 8 9 10	91.649	97
10ll	4	95	191,015	0.4	0.4	14	14			1 2 4 5 6 7 8 9	95.233	100
10ll	4	99	237,997	0.4	0.3	17	9			1 2 4 5 6 7 9	99.011	95
10lt	4	80	205,008	0.9	1.0	57	34			1 4 5 6 8 10	84.771	100
10lt	4	85	205,516	0.4	0.8	21	13			1 4 5 6 8 10	85	100
10lt	4	90	219,696	1.3	1.5	103	109			1 2 3 4 5 8 10	90	85
10lt	4	95	225,507	0.5	0.7	7	19			1 2 4 5 6 9 10	95	100
10lt	4	99	261,422	0.5	0.5	40	64			1 2 4 5 6 9 10	99	95
10tl	4	80	220,840	0.7	1.0	75	65			3 4 5 8 10	80	100
10tl	4	85	223,773	0.7	1.0	39	47			1 3 4 8 10	85.904	100
10tl	4	90	229,727	0.9	1.0	78	79			1 2 3 4 5 8 10	90	100
10tl	4	95	241,911	0.5	0.6	39	84			1 2 4 5 8 10	95.297	100
10tl	4	99	270,024	0.6	0.8	46	63			1 2 4 5 6 8 9	99	95
10tt	4	80	218,689	0.7	0.7	10	16			1 4 5 6 9	83.929	100
10tt	4	85	219,898	0.7	1.0	13	28			1 2 4 5 10	85	100
10tt	4	90	234,227	0.9	1.1	54	52			1 4 5 6 10	91.125	100
10tt	4	95	239,996	0.7	0.9	4	14			1 2 4 5 6 9 10	95	100

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Instance	r	100α	Obj. Val.	Time (sec)		B&B nodes		Opt. Gap. (%)		Hubs	Min S.L. (%)	Connectivity (%)
				$M1$	$M2$	$M1$	$M2$	$M1$	$M2$			
10tt	4	99	274,651	0.5	0.4	26	45			1 4 5 6 9 10	99	86
20ll	4	80	220,148	348.1	328.2	803	253			6 7 14 15	80	100
20ll	4	85	221,406	120.4	201.4	219	169			6 7 14 15	85	100
20ll	4	90	224,011	103.8	202.7	108	202			6 7 14 15	90	100
20ll	4	95	234,968	204.1	136.9	573	383			6 7 14 15	95	100
20ll	4	99	265,527	61.0	404.9	207	4,428			6 7 14 15	99	100
20lt	4	80	226,233	483.4	477.9	1,866	2,268			6 8 10 13 14	80	100
20lt	4	85	230,209	648.4	310.5	2,354	1,008			6 8 10 13 14	85	100
20lt	4	90	235,499	379.7	289.6	1,957	410			6 9 10 12 14	90	100
20lt	4	95	245,594	303.8	277.2	2,529	964			6 10 12 13 14	95	100
20lt	4	99	279,859	131.2	150.2	2,252	3,648			6 9 10 14 19	99	100
20tl	4	80	244,786	297.7	173.7	573	112			7 10 19	80.233	100
20tl	4	85	247,067	188.4	213.2	150	105			7 10 19	85	100
20tl	4	90	252,889	154.5	169.1	242	135			7 9 10 11	90	100
20tl	4	95	263,328	186.1	140.2	300	127			7 10 11	95	100
20tl	4	99	293,576	48.2	42.5	65	41			7 10 11	99	100
20tt	4	80	259,660	481.7	233.8	1,900	217			6 8 9 10 19	80	100
20tt	4	85	264,741	626.3	272.7	2,045	324			6 9 10 12	85	100
20tt	4	90	269,977	231.3	290.4	885	376			6 8 9 10	90	100
20tt	4	95	284,823	253.4	186.2	1,095	326			5 6 8 10	95	100
20tt	4	99	317,737	59.9	45.2	563	572			6 8 10	99.004	100
25ll	4	80	223,132	1,844.4	3,734.6	1,003	495			8 9 14 17 18	80.855	100
25ll	4	85	226,923	1,713.3	3,747.0	1,914	1,426			8 9 14 17 18	85	100
25ll	4	90	230,435	1,890.9	2,364.7	1,674	350			7 8 14 17 23	90	100
25ll	4	95	242,492	1,902.6	1,939.6	3,306	1,146			7 8 14 17 18 19	95	100
25ll	4	99	268,493	472.0	635.9	1,321	1,223			7 8 14 18 19	99	100
25lt	4	80	240,723	44,192.0	10,228.3	21,938	1,263			2 6 9 12 14 19	80	100
25lt	4	85	244,766	34,522.3	16,457.2	33,297	19,604			4 6 9 12 14 19	85	100
25lt	4	90	250,301	21,694.4	6,097.5	15,368	1,298			6 9 12 14 19	90	100
25lt	4	95	260,793	13,934.1	12,205.2	18,372	6,047			6 9 12 14 19	95	100
25lt	4	99	288,843	10,983.2	4,033.9	20,501	14,967			9 12 13 14 19	99	100
25tl	4	80	277,671	5,091.4	2,812.5	2,489	105			9 14	80	100
25tl	4	85	281,196	5,195.8	2,173.2	3,195	90			9 14	85.092	100
25tl	4	90	285,296	2,297.2	2,241.0	1,070	114			9 14	90.415	100
25tl	4	95	294,422	3,261.8	1,318.5	1,539	114			9 14	95.382	100
25tl	4	99	322,051	418.6	197.8	294	69			9 14	99.002	100

Table 1 continued from previous page

				Time (sec)		B&B nodes		Opt. Gap. (%)				
Instance	r	100α	Obj. Val.	$M1$	$M2$	$M1$	$M2$	$M1$	$M2$	Hubs	Min S.L. (%)	Connectivity (%)
25tt	4	80	287,276	29,038.3	1,644.9	31,300	181			6 9 12 14	80	100
25tt	4	85	293,115	Time	2,309.5	41,838	308	0.882		9 13 14	85	100
25tt	4	90	296,614	79,938.0	4,447.8	80,338	3,854			9 13 14	90	100
25tt	4	95	303,067	26,640.5	17,751.3	41,926	36,743			9 12 13 14	95	100
25tt	4	99	324,584	2,165.5	1,729.2	3,064	2,051			9 13 14	99	100
40ll	4	80	Time			1,144	118	4.731	5.431			
40ll	4	85	Time			1,256	105	6.751	4.042			
40ll	4	90	Time			1,422	142	4.527	5.855			
40ll	4	95	246,371	Time	73,959.1	2,606	629	0.733		6 14 29 30	95.039	100
40ll	4	99	Time			2,995	4,213	3.227	0.004			
40lt	4	80	Time			1,373	42	8.894	6.605			
40lt	4	85	271,585	Time	Time	1,266	362	10.208	6.625	5 14 19 30	85	100
40lt	4	90	Time			1,602	153	11.819	6.978			
40lt	4	95	Time			1,602	529	15.266	7.179			
40lt	4	99	Time			1,958	1,289	13.341	6.622			
40tl	4	80	270,793	Time	52,202.0	592	102	2.238		14 19 21	80.897	100
40tl	4	85	272,107	Time	42,837.0	723	216	1.957		14 19 21	85	100
40tl	4	90	283,775	Time	29,283.6	539	108	2.487		14 19 21	90.744	100
40tl	4	95	295,461	74,656.5	20,236.7	2,029	323			6 14 19 21	95	100
40tl	4	99	Time			1,761	3,445	0.129	1.423			
40tt	4	80	308,003	Time	67,381.6	1,011	857	6.560		6 14 19 25	80	100
40tt	4	85	318,758	Time	40,717.2	1,331	461	7.570		10 14 19	86.167	100
40tt	4	90	Time			658	988	5.469	0.130			
40tt	4	95	Time			1,239	2,203	6.280	0.046			
40tt	4	99	351,662	Time	19,345.8	3,945	891	5.791		6 14 19	99	100

Table 2: Detailed results for formulations $M1$ and $M3$ for the COL data set.

Instance	r	100α	Obj. Val.	Time (sec)		B&B nodes		Opt. Gap. (%)		Hubs	Min S.L. (%)	Connectivity (%)
				$M1$	$M2$	$M1$	$M2$	$M1$	$M2$			
10-1	2	80	523,384	1.0	0.5	81	40			3 5 8	80.739	100
10-1	2	85	528,890	0.3	0.4	26	18			3 8	85	100
10-1	2	90	540,297	0.0	0.0	0	0					
10-1	2	95	540,297	0.0	0.0	0	0					
10-1	2	99	540,297	0.0	0.0	0	0					
10-2	2	80	532,414	2.1	1.1	428	147			3 8	80	100
10-2	2	85	540,183	0.5	0.4	110	57			5 8	86.759	100
10-2	2	90	540,297	0.0	0.0	0	0					
10-2	2	95	540,297	0.0	0.0	0	0					
10-2	2	99	540,297	0.0	0.0	0	0					
10-3	2	80	528,755	0.8	0.7	145	69			5 8	80	100
10-3	2	85	540,183	0.6	0.3	88	46			5 8	88.038	100
10-3	2	90	540,297	0.0	0.0	0	0					
10-3	2	95	540,297	0.0	0.0	0	0					
10-3	2	99	540,297	0.0	0.0	0	0					
10-4	2	80	528,235	0.7	1.2	195	151			2 4	80	100
10-4	2	85	535,488	0.3	0.4	55	25			2 4	85	100
10-4	2	90	539,544	0.0	0.0	0	0			2 4	90.116	100
10-4	2	95	540,297	0.0	0.0	0	0					
10-4	2	99	540,297	0.0	0.0	0	0					
20-1	2	80	530,834	193.7	163.4	1,654	552			2 4 6	80	100
20-1	2	85	539,302	58.9	41.0	615	237			2 4 8	85	100
20-1	2	90	551,120	5.9	4.1	323	38			3 6	90.07	100
20-1	2	95	552,707	0.0	0.0	0	0					
20-1	2	99	552,707	0.0	0.0	0	0					
20-2	2	80	530,594	302.8	191.5	2,708	751			4 6 8	80	100
20-2	2	85	537,822	45.9	47.9	615	265			6 9	85	100
20-2	2	90	545,266	4.1	3.4	127	28			6 9	90	100
20-2	2	95	552,707	0.0	0.0	0	0					
20-2	2	99	552,707	0.0	0.0	0	0					
20-3	2	80	534,095	566.6	248.7	3,082	899			1 4 8	80.11	100
20-3	2	85	541,342	58.1	36.2	653	216			4 8	85	100
20-3	2	90	552,707	4.2	2.9	175	24					
20-3	2	95	552,707	0.0	0.0	0	0					
20-3	2	99	552,707	0.0	0.0	0	0					

Table 2 continued from previous page

Instance	r	100α	Obj. Val.	Time (sec)		B&B nodes		Opt. Gap. (%)		Hubs	Min S.L. (%)	Connectivity (%)
				$M1$	$M2$	$M1$	$M2$	$M1$	$M2$			
20-4	2	80	518,371	48.1	56.9	454	156			2 4 6	80.302	100
20-4	2	85	534,227	30.7	30.6	454	284			2 4	85.373	100
20-4	2	90	543,374	2.0	2.2	75	27			2 4	90.24	100
20-4	2	95	552,707	0.0	0.0	0	0					
20-4	2	99	552,707	0.0	0.0	0	0					
25-1	2	80	537,072	1,949.6	1,560.4	5,349	900			3 5 11	80	100
25-1	2	85	542,540	248.6	182.8	888	240			3 5 11	85	100
25-1	2	90	559,537	86.2	37.6	542	105					
25-1	2	95	559,537	0.0	0.0	0	0					
25-1	2	99	559,537	0.0	0.0	0	0					
25-2	2	80	532,774	1,558.7	944.7	2,313	465			3 7 11	80	100
25-2	2	85	544,604	1,199.7	379.2	2,248	391			3 5 11	85	100
25-2	2	90	556,801	156.7	29.2	1,248	95			4 7	90.065	100
25-2	2	95	559,537	0.0	0.0	0	0					
25-2	2	99	559,537	0.0	0.0	0	0					
25-3	2	80	537,394	5,734.0	1,701.3	5,733	1,064			7 10 19	80	100
25-3	2	85	543,930	1,093.0	416.8	1,911	406			10 19	85	100
25-3	2	90	556,036	30.7	27.2	279	44			10 19	90	100
25-3	2	95	559,537	0.0	0.0	0	0					
25-3	2	99	559,537	0.0	0.0	0	0					
25-4	2	80	532,478	1,147.1	669.3	4,067	798			3 5 7 11	80	100
25-4	2	85	540,726	187.1	235.3	897	287			3 5 11	85	100
25-4	2	90	549,492	26.3	19.0	243	43			3 5 11	90	100
25-4	2	95	559,537	0.0	0.0	0	0					
25-4	2	99	559,537	0.0	0.0	0	0					
40-1	2	80	Time			2,276	380	3.397	3.292			
40-1	2	85	531,560	Time	54,490.0	5,934	928	1.857		8 10 34	85.013	100
40-1	2	90	535,589	9,725.3	2,077.7	2,267	184			8 34	90.208	100
40-1	2	95	563,790	18.4	10.0	193	35					
40-1	2	99	563,790	0.0	0.0	0	0					
40-2	2	80	Time			3,401	508	4.033	3.650			
40-2	2	85	Time			3,549	631	3.685	1.849			
40-2	2	90	547,444	Time	8,210.6	3,310	771	0.404		10 17 18	90	100
40-2	2	95	563,790	31.3	86,085.0	140	86,403					
40-2	2	99	563,790	0.0	0.0	0	0					
40-3	2	80	Time			3,640	520	3.153	0.716			

Table 2 continued from previous page

Instance	r	100α	Obj. Val.	Time (sec)		B&B nodes		Opt. Gap. (%)		Hubs	Min S.L. (%)	Connectivity (%)
				$M1$	$M2$	$M1$	$M2$	$M1$	$M2$			
40-3	2	85	525,655	38,124.0	16,667.2	2,870	424			6 7 10	85	100
40-3	2	90	540,742	8,014.1	1,807.8	3,379	306			7 10 18	90.007	100
40-3	2	95	563,790	0.3	0.3	0	0					
40-3	2	99	563,790	0.0	0.0	0	0					
40-4	2	80	Time			4,200	398	5.622	3.021			
40-4	2	85	530,740	Time	45,695.8	4,098	399			8 18	85	100
40-4	2	90	547,041	18,282.8	7,165.2	5,395	476			4 8 18	90	100
40-4	2	95	563,790	2.2	0.4	0	0					
40-4	2	99	563,790	0.0	0.0	0	0					
10-1	3	80	462,210	1.8	6.7	253	1,136			1 2 3 4 7 8	80	86
10-1	3	85	471,123	3.3	7.0	359	1,023			2 3 4 7 8	85	90
10-1	3	90	485,007	4.6	5.4	559	813			2 3 4 7 8	90	80
10-1	3	95	510,618	2.0	3.2	335	520			2 3 4 10	95	83
10-1	3	99	540,297	0.1	0.1	6	0					
10-2	3	80	473,379	3.5	17.2	680	4,479			1 2 3 4 8 10	80	73
10-2	3	85	484,816	5.0	18.0	773	4,015			1 2 3 4 8 10	85	66
10-2	3	90	498,021	6.6	14.2	1,174	2,191			2 3 4 7 8	90	80
10-2	3	95	519,654	5.0	8.5	1,171	1,630			2 4 7 8	95	100
10-2	3	99	540,297	0.1	0.1	0	0					
10-3	3	80	475,969	2.9	12.0	516	1,814			2 3 4 7 8 10	80	86
10-3	3	85	484,140	4.3	7.3	579	1,281			2 3 4 7 8 10	85	80
10-3	3	90	495,490	4.7	8.2	676	1,140			2 3 4 7 8	90	80
10-3	3	95	517,590	3.4	5.0	945	1,179			2 4 7 8	95	100
10-3	3	99	540,297	0.1	0.0	1	0					
10-4	3	80	454,475	1.3	2.7	172	249			1 2 3 4 7 8	80	86
10-4	3	85	457,492	1.1	2.4	78	120			1 2 3 4 7 8	85	73
10-4	3	90	476,609	2.7	4.8	398	843			2 3 4 7 8	90	80
10-4	3	95	499,599	1.2	2.0	171	247			2 3 4 7	95.015	100
10-4	3	99	539,544	0.1	0.0	1	1			2 4	99.358	100
20-1	3	80	490,566	929.6	35,030.6	4,045	279,698			1 2 3 4 9 13 18	80	95
20-1	3	85	497,542	2,802.6	10,823.4	13,660	124,229			1 2 3 4 15 18	85	86
20-1	3	90	502,514	1,363.0	1,395.9	6,609	2,770			1 2 3 4 13	90	100
20-1	3	95	516,812	1,002.3	741.9	4,634	1,435			2 4 6	95.266	100
20-1	3	99	548,271	51.6	12.9	1,032	172			2 4	99	100
20-2	3	80	492,221	1,406.4	906.3	6,144	2,502			1 2 4 9 14 15	80	93
20-2	3	85	496,886	2,028.8	1,305.3	7,355	3,479			1 2 4 9 14 15	85	93

Table 2 continued from previous page

Instance	r	100α	Obj. Val.	Time (sec)		B&B nodes		Opt. Gap. (%)		Hubs	Min S.L. (%)	Connectivity (%)
				$M1$	$M2$	$M1$	$M2$	$M1$	$M2$			
20-2	3	90	503,122	1,702.9	1,358.1	8,306	3,190			1 2 4 9 14 15	90	86
20-2	3	95	517,148	1,033.1	838.2	4,259	1,494			4 6 8	95	100
20-2	3	99	542,229	18.6	11.7	352	89			6 9	99	100
20-3	3	80	492,065	863.6	1,346.2	4,006	13,949			1 2 4 9 15 16 18	80	100
20-3	3	85	496,569	1,267.4	2,445.1	5,541	16,304			1 2 4 9 15 16 18	85	80
20-3	3	90	506,482	1,542.6	961.9	7,334	4,295			1 2 4 9 15 16 18	90	85
20-3	3	95	520,169	822.0	901.9	4,299	2,723			1 8 9	95	100
20-3	3	99	547,228	15.0	11.6	277	129			4 8	99	100
20-4	3	80	488,848	885.1	896.6	5,590	2,679			1 2 4 9 15 18	80	100
20-4	3	85	492,627	862.7	1,315.1	5,854	5,614			1 2 4 9 14 15	85	100
20-4	3	90	495,968	541.3	587.8	2,047	1,085			1 2 4 9 14 15	90	100
20-4	3	95	507,552	375.9	297.9	1,868	2,261			2 4 6 15	95.086	100
20-4	3	99	536,534	3.6	3.3	89	23			2 4 8	99	100
25-1	3	80	499,634	7,255.0	6,217.9	4,714	2,141			1 3 4 5 10 21	80	100
25-1	3	85	506,103	19,899.9	21,665.5	14,104	13,861			1 3 4 5 10 21	85	100
25-1	3	90	514,846	34,001.2	21,146.4	29,779	9,075			1 3 4 5 10	90	100
25-1	3	95	526,177	18,413.8	8,649.8	16,308	6,423			2 5 11	95	100
25-1	3	99	548,326	110.0	163.1	557	612			3 5 11	99	100
25-2	3	80	496,212	9,970.6	9,748.2	11,783	20,727			1 3 4 5 19 20	80	93
25-2	3	85	501,982	23,342.3	20,561.7	23,376	29,612			1 3 4 5 19 20	85	100
25-2	3	90	509,091	20,240.4	24,056.8	34,560	40,109			1 3 4 5 19 20	90	93
25-2	3	95	523,792	14,099.8	7,905.4	14,178	4,776			3 4 5 7 20	95	90
25-2	3	99	549,609	281.8	76.3	1,195	152			7 12	99.007	100
25-3	3	80	497,548	4,697.3	4,473.9	6,047	2,359			1 3 4 5 19 21	80	100
25-3	3	85	503,271	6,266.2	5,892.1	6,473	2,430			1 3 4 5 10 21	85	100
25-3	3	90	511,279	10,754.0	11,100.4	11,187	7,470			1 3 4 5 10	90	90
25-3	3	95	520,514	4,180.4	3,660.5	3,524	1,612			3 5 7 10	95	100
25-3	3	99	551,181	205.3	87.4	1,010	162			10 19	99.028	100
25-4	3	80	500,677	11,417.9	4,734.5	12,162	4,732			1 3 5 7 20 22	80	93
25-4	3	85	505,177	13,983.3	12,369.8	11,722	17,113			1 3 5 7 20 22	85	100
25-4	3	90	510,841	16,708.7	16,843.8	11,961	3,688			1 3 5 7	90	100
25-4	3	95	520,297	3,858.4	4,124.6	3,516	1,183			3 5 7	95	100
25-4	3	99	544,098	42.4	52.0	270	346			3 5 11	99	100
40-1	3	80	Time			1,529	577	1.817	1.041			
40-1	3	85	Time			1,217	500	3.249	2.407			
40-1	3	90	Time			2,074	478	4.258	2.539			

Table 2 continued from previous page

Instance	r	100α	Obj. Val.	Time (sec)		B&B nodes		Opt. Gap. (%)		Hubs	Min S.L. (%)	Connectivity (%)
				$M1$	$M2$	$M1$	$M2$	$M1$	$M2$			
40-1	3	95	Time			2,852	716	3.360	2.824			
40-1	3	99	532,172	22,509.8	13,274.2	2,542	555			8 34	99.002	100
40-2	3	80	Time			1,588	391	1.841	2.352			
40-2	3	85	Time			2,483	363	3.413	3.043			
40-2	3	90	Time			1,662	380	4.908	3.721			
40-2	3	95	Time			3,228	372	6.843	4.347			
40-2	3	99	536,790	Time	26,756.1	5,216	1,629	0.466		10 17 18	99	66
40-3	3	80	Time			2,672	290	3.493	3.499			
40-3	3	85	Time			1,600	140	5.749	3.329			
40-3	3	90	Time			2,247	361	3.384	4.848			
40-3	3	95	Time			1,771	411	4.711	5.288			
40-3	3	99	532,358	17,021.4	4,818.5	1,357	263			7 18	99.013	100
40-4	3	80	Time			2,480	382	1.359	0.830			
40-4	3	85	Time			2,728	223	2.756	4.151			
40-4	3	90	Time			1,823	168	3.337	4.762			
40-4	3	95	Time			2,233	1,052	5.913	4.882			
40-4	3	99	539,470	49,498.1	13,484.6	5,138	1,313			8 17 18	99	100
10-1	4	80	438,626	0.6	1.2	36	37			1 2 3 4 8 10	80	86
10-1	4	85	443,156	0.7	1.6	50	60			1 2 3 4 8 10	85	86
10-1	4	90	450,929	1.4	3.1	211	618			1 2 3 4 8 10	90	86
10-1	4	95	463,803	2.3	5.2	277	1,204			1 2 3 4 8 10	95	80
10-1	4	99	497,332	3.1	4.7	386	855			2 3 4 7 8	99	70
10-2	4	80	448,330	1.4	1.9	68	146			1 2 3 4 8 10	80	80
10-2	4	85	453,758	1.5	4.1	145	427			1 2 3 4 8 10	85	80
10-2	4	90	460,491	2.0	5.6	223	728			1 2 3 4 8 10	90	80
10-2	4	95	475,537	3.4	13.3	529	4,690			1 2 3 4 8 10	95	73
10-2	4	99	509,344	9.0	12.2	1,637	3,247			1 2 3 4	99	100
10-3	4	80	449,824	1.0	1.6	52	102			1 2 3 4 7 8 10	80	85
10-3	4	85	455,147	1.3	5.0	102	1,165			1 2 3 4 7 8 10	85	80
10-3	4	90	463,703	2.0	9.5	188	2,974			1 2 3 4 7 8 10	90	76
10-3	4	95	478,468	3.3	8.9	610	2,485			2 3 4 7 8 10	95	80
10-3	4	99	508,630	5.6	7.6	1,024	2,086			2 3 4 5 7	99	100
10-4	4	80	442,394	0.9	2.3	149	475			1 2 3 4 8 10	80	86
10-4	4	85	446,816	1.4	3.6	272	1,133			1 2 3 4 7 8	85	73
10-4	4	90	476,609	1.2	3.2	153	310			2 3 4 7 8	90	80
10-4	4	95	455,373	1.2	2.3	201	304			1 2 3 4 7 8	95.276	73

Table 2 continued from previous page

Instance	r	100α	Obj. Val.	Time (sec)		B&B nodes		Opt. Gap. (%)		Hubs	Min S.L. (%)	Connectivity (%)
				$M1$	$M2$	$M1$	$M2$	$M1$	$M2$			
10-4	4	99	490,586	2.8	3.9	396	927			2 3 4 7 8	99	80
20-1	4	80	476,069	141.6	494.4	750	3,207			1 2 3 4 15 18	80	100
20-1	4	85	479,136	264.5	2,976.8	1,282	22,307			1 2 3 4 15 18	85	100
20-1	4	90	483,175	441.1	20,474.1	2,842	179,388			1 2 3 4 9 15 18	90	95
20-1	4	95	492,012	1,438.0	Time	6,027	566,827		0.282	1 2 3 4 15 18	95	100
20-1	4	99	510,216	1,905.9	2,145.5	10,236	5,485			1 2 4 6 13	99	100
20-2	4	80	481,789	531.4	623.0	2,623	2,116			1 4 9 15 16 18	80	100
20-2	4	85	484,173	487.0	1,602.0	2,247	5,770			1 4 9 15 18	85	100
20-2	4	90	488,356	1,126.3	3,120.6	5,174	25,321			1 2 4 9 15 18	90	93
20-2	4	95	493,077	1,615.6	1,287.0	5,884	2,266			1 2 4 9 14 15	95	86
20-2	4	99	510,349	1,205.7	1,105.9	6,452	2,585			1 2 4 9 15	99	80
20-3	4	80	479,557	111.1	245.2	570	953			1 2 4 9 15 16 18	80	95
20-3	4	85	482,321	154.5	529.9	870	3,010			1 2 4 9 15 16 18	85	95
20-3	4	90	485,360	249.2	1,159.1	1,116	12,358			1 2 4 9 15 16 18	90	85
20-3	4	95	492,658	587.3	1,104.2	3,784	7,601			1 2 4 9 15 16 18	95	95
20-3	4	99	513,745	1,393.2	1,508.2	6,778	4,798			1 2 8 9 15	99	90
20-4	4	80	477,981	232.0	771.9	1,264	4,322			1 2 3 4 9 15 18	80	85
20-4	4	85	480,366	358.3	1,138.4	1,961	7,692			1 2 4 9 15 18	85	100
20-4	4	90	483,045	383.1	721.0	2,126	2,458			1 2 4 9 15 18	90	100
20-4	4	95	489,164	748.5	561.1	4,348	1,492			1 2 4 9 15 18	95	100
20-4	4	99	499,197	295.4	371.9	1,407	1,086			1 2 4 9 15	99	100
25-1	4	80	491,222	2,682.8	14,155.5	4,126	15,351			1 3 4 5 19 22	80	100
25-1	4	85	493,015	3,430.8	6,544.9	3,437	7,638			1 3 4 5 10 21	85	100
25-1	4	90	494,848	3,790.1	4,558.9	4,036	1,297			1 3 4 5 19 21	90	100
25-1	4	95	501,321	8,477.6	8,714.5	5,623	2,208			1 3 4 5 10 21	95	100
25-1	4	99	519,815	17,682.5	13,160.9	16,512	6,024			3 4 5 10	99	100
25-2	4	80	486,374	1,685.9	4,822.6	1,793	5,770			1 3 4 5 19 20	80	93
25-2	4	85	489,426	1,957.3	4,028.4	3,758	6,522			1 3 4 5 19 20	85	93
25-2	4	90	491,557	3,066.5	4,291.7	4,410	1,634			1 3 4 5 19 20	90	93
25-2	4	95	497,389	10,583.9	8,705.8	11,673	4,166			1 3 4 5 19 20	95	93
25-2	4	99	517,902	18,912.5	17,793.2	22,242	19,799			3 4 5 7 20	99	80
25-3	4	80	487,566	1,168.5	2,250.7	1,234	987			1 3 4 5 19 21	80	100
25-3	4	85	489,245	1,311.1	1,805.5	1,275	1,040			1 3 4 5 19 21	85	100
25-3	4	90	491,668	2,097.4	2,703.2	2,333	1,301			1 3 4 5 19 21	90	100
25-3	4	95	498,415	4,118.3	5,983.7	4,753	1,798			1 3 4 5 19 21	95	100
25-3	4	99	516,843	7,362.5	7,086.2	6,432	3,243			3 7 10	99	100

Table 2 continued from previous page

Instance	r	100α	Obj. Val.	Time (sec)		B&B nodes		Opt. Gap. (%)		Hubs	Min S.L. (%)	Connectivity (%)
				$M1$	$M2$	$M1$	$M2$	$M1$	$M2$			
25-4	4	80	491,661	1,874.6	2,905.6	2,436	2,299			1 3 5 12 19 20 22	80	100
25-4	4	85	494,412	4,262.8	19,133.7	5,398	45,427			1 3 5 12 19 20 22	85	95
25-4	4	90	496,446	6,353.3	4,172.2	7,122	3,162			1 3 5 12 19 20 22	90	95
25-4	4	95	501,112	9,633.1	5,663.3	10,062	7,120			1 3 5 7 20 22	95	93
25-4	4	99	516,401	12,220.2	9,934.3	7,031	3,909			1 3 5 7	99	100
40-1	4	80	475,113	31,121.7	84,350.6	945	2,145			1 8 19 32 37	80	100
40-1	4	85	478,097	28,046.3	Time	845	954		0.085	1 8 19 32 37	85	100
40-1	4	90	Time			1,504	577	0.485	0.597			
40-1	4	95	Time			1,693	441	2.388	1.136			
40-1	4	99	Time			3,138	350	6.148	4.090			
40-2	4	80	482,179	37,028.3	Time	1,662	935		0.388	1 4 6 19 32 38	80	100
40-2	4	85	484,439	66,714.5		2,197	525		0.494	1 4 6 19 32 38	85	100
40-2	4	90	Time			2,011	454	0.639	0.471			
40-2	4	95	Time			1,746	430	2.304	2.595			
40-2	4	99	Time			2,471	411	5.458	5.061			
40-3	4	80	Time			1,947	483	1.576	1.469			
40-3	4	85	Time			2,224	296	1.329	2.802			
40-3	4	90	Time			2,486	347	2.445	2.879			
40-3	4	95	Time			926	350	3.258	4.046			
40-3	4	99	Time			544	458	3.990	4.380			
40-4	4	80	477,762	10,899.2	25,899.0	284	142			1 5 8 32 38	80	100
40-4	4	85	478,852	26,787.7	50,099.8	958	659			1 5 8 32 38	85	100
40-4	4	90	481,236	34,121.1	55,763.0	1,160	1,165			1 5 8 32 38	90	100
40-4	4	95	Time			2,456	450	0.469	1.908			
40-4	4	99	Time			2,160	708	4.486	3.859			