Appendix of A Two-layer Heterogeneous Ant Colony System with Applications in Tape Carrier Packaging

It should be noted that ACS, IMMAS, GA, SA and PSO in this experiment were all improved by using the two-layer solution framework and the candidate cluster augmentation strategy.

Appendix A. The experimental results of the 3×1 sucker matrix configuration.

No.	Amount	Methods	e_n	e_{max}	*std*	$\bar{n}$	$\overline{N_c}$	t_w	e_t	p-value
		THACS	3.328	3.367	0.033	177.020	51.560	53.193	3.042	–
		ACS	3.267	3.360	0.068	176.640	58.260	54.067	2.991	2.77E-07
		IMMAS	3.280	3.366	0.063	176.960	53.460	53.949	3.002	8.13E-06
1	250	GA	3.259	3.363	0.051	174.200	49.440	53.454	2.980	3.96E-12
		SA	3.247	3.356	0.071	173.800	51.800	53.531	2.969	2.99E-10
		PSO	3.255	3.355	0.059	174.400	50.860	53.581	2.977	5.55E-11
		Greedy	2.992	3.315	0.165	206.200	672.040	68.928	2.789	1.22E-19
		THACS	3.337	3.465	0.065	194.260	43.340	58.219	3.073	–
		ACS	3.284	3.392	0.067	195.100	43.860	59.405	3.029	1.21E-04
		IMMAS	3.285	3.384	0.080	195.400	43.600	59.484	3.030	5.71E-04
2	275	GA	3.265	3.381	0.076	192.420	41.760	58.941	3.009	1.72E-06
		SA	3.238	3.383	0.094	191.080	42.760	59.005	2.985	2.65E-08
		PSO	3.275	3.385	0.078	191.120	42.320	58.357	3.017	3.71E-05
		Greedy	3.033	3.283	0.142	227.200	569.480	74.903	2.843	1.82E-21
		THACS	3.315	3.416	0.061	212.100	35.760	63.984	3.075	–
		ACS	3.238	3.303	0.054	209.460	38.740	64.687	3.006	1.62E-09
		IMMAS	3.274	3.359	0.050	210.600	36.740	64.332	3.038	4.27E-04
3	300	GA	3.233	3.375	0.088	207.260	33.960	64.117	2.999	5.55E-07
		SA	3.218	3.283	0.046	205.180	33.400	63.759	2.984	4.68E-14
		PSO	3.234	3.359	0.060	205.680	334.640	63.607	2.998	1.62E-09
		Greedy	2.990	3.262	0.121	257.700	520.820	86.183	2.826	6.09E-27
		THACS	3.346	3.457	0.045	231.240	29.580	69.110	3.120	–
		ACS	3.302	3.352	0.040	229.260	31.940	69.438	3.080	1.27E-06
		IMMAS	3.317	3.410	0.045	231.300	30.920	69.735	3.095	1.68E-03
4	325	GA	3.270	3.345	0.066	227.260	29.620	69.499	3.051	1.67E-09
		SA	3.263	3.326	0.037	227.020	29.080	69.571	3.044	1.33E-16
		PSO	3.287	3.328	0.032	229.160	29.700	69.710	3.067	4.86E-11
		Greedy	2.945	3.135	0.146	265.500	403.820	90.159	2.790	4.48E-26
		THACS	3.377	3.459	0.040	246.600	25.900	73.015	3.161	–
		ACS	3.323	3.403	0.060	246.240	27.080	74.106	3.113	9.28E-07
		IMMAS	3.340	3.425	0.043	246.800	26.380	73.897	3.128	2.02E-05
5	350	GA	3.292	3.387	0.047	243.160	25.080	73.855	3.084	5.28E-16
		SA	3.273	3.371	0.046	242.060	25.740	73.961	3.066	6.04E-21
		PSO	3.286	3.389	0.053	245.660	25.280	74.764	3.080	9.11E-16
		Greedy	3.105	3.358	0.122	281.180	366.560	90.570	2.942	9.27E-22

Appendix B. The experimental results of the 3×2 sucker matrix configuration.

No.	Amount	Methods	e_n	e_{max}	*std*	$\bar{n}$	$\overline{N_c}$	t_w	e_t	p-value
		THACS	4.898	4.961	0.053	168.820	86.460	34.464	4.278	–
		ACS	4.808	4.937	0.075	166.740	86.520	34.678	4.202	7.40E-10
		IMMAS	4.818	4.939	0.056	167.520	83.820	34.773	4.212	6.85E-11
1	250	GA	4.792	4.901	0.053	163.500	74.260	34.121	4.179	1.45E-16
		SA	4.729	4.787	0.055	162.320	84.560	34.323	4.128	3.27E-28
		PSO	4.787	4.850	0.058	164.560	76.260	34.375	4.179	1.80E-16
		Greedy	3.354	3.613	0.147	186.300	1196.720	55.546	3.077	2.67E-60
		THACS	4.843	4.935	0.060	185.900	73.280	38.385	4.285	–
		ACS	4.753	4.913	0.066	186.520	74.520	39.243	4.216	1.68E-10
		IMMAS	4.778	4.854	0.050	184.560	75.120	38.629	4.230	5.42E-08
2	275	GA	4.749	4.895	0.066	182.260	69.200	38.378	4.202	3.50E-11
		SA	4.660	4.883	0.096	184.320	71.020	39.554	4.137	1.01E-18
		PSO	4.738	4.836	0.062	184.200	68.980	38.880	4.198	1.09E-13
		Greedy	3.383	3.783	0.221	212.700	936.340	62.875	3.134	7.95E-46
		THACS	4.760	4.852	0.076	203.120	54.980	42.616	4.266	–
		ACS	4.678	4.809	0.086	199.860	57.840	42.708	4.189	2.12E-06
		IMMAS	4.683	4.827	0.092	204.220	56.140	43.600	4.202	1.52E-05
3	300	GA	4.659	4.785	0.083	196.540	47.920	42.175	4.166	6.70E-09
		SA	4.621	4.731	0.084	193.200	58.740	41.809	4.127	8.78E-14
		PSO	4.645	4.751	0.091	195.660	48.120	42.112	4.153	7.32E-10
		Greedy	3.741	4.125	0.157	235.520	605.320	62.956	3.466	4.72E-51
		THACS	4.870	4.997	0.079	214.620	51.900	44.074	4.373	–
		ACS	4.779	4.913	0.087	218.820	52.200	45.791	4.308	3.40E-07
		IMMAS	4.787	4.912	0.065	214.700	53.540	44.855	4.307	1.13E-07
4	325	GA	4.720	4.775	0.033	214.800	50.760	45.513	4.252	6.50E-19
		SA	4.708	4.902	0.110	212.060	51.540	45.047	4.237	4.46E-13
		PSO	4.767	4.842	0.054	213.460	50.860	44.783	4.288	2.68E-11
		Greedy	3.292	3.772	0.217	257.380	573.400	78.180	3.094	1.09E-50
		THACS	4.886	4.968	0.066	233.740	44.460	47.834	4.424	–
		ACS	4.804	4.933	0.065	236.220	45.460	48.931	4.380	1.10E-08
		IMMAS	4.828	4.944	0.078	235.000	46.320	48.923	4.358	1.16E-04
5	350	GA	4.798	4.918	0.097	234.660	41.760	48.607	4.377	7.87E-07
		SA	4.738	4.936	0.104	234.200	42.780	48.809	4.352	6.61E-13
		PSO	4.754	4.938	0.095	233.720	44.200	49.332	4.302	3.37E-12
		Greedy	3.437	3.775	0.169	279.620	502.000	81.353	3.238	5.26E-56

Appendix C. The experimental results of the 3×3 sucker matrix configuration.

No.	Amount	Methods	e_n	e_{max}	*std*	$\bar{n}$	$\overline{N_c}$	t_w	e_t	p-value
		THACS	5.407	5.549	0.074	160.420	87.380	29.670	4.627	–
		ACS	5.325	5.448	0.070	159.800	101.700	30.010	4.564	1.30E-07
		IMMAS	5.333	5.466	0.120	161.320	95.000	30.251	4.576	3.71E-04
1	250	GA	5.287	5.405	0.045	160.260	84.960	30.313	4.538	1.70E-15
		SA	5.307	5.395	0.057	158.260	86.940	29.822	4.545	2.62E-11
		PSO	5.309	5.426	0.107	158.600	84.880	29.875	4.548	6.96E-07
		Greedy	3.423	4.047	0.326	181.620	1506.020	53.055	3.128	6.90E-43
		THACS	5.450	5.607	0.111	176.400	77.200	32.366	4.721	–
		ACS	5.369	5.531	0.106	175.340	85.040	32.657	4.656	3.31E-04
		IMMAS	5.379	5.461	0.059	179.400	80.700	33.351	4.678	1.57E-04
2	275	GA	5.346	5.518	0.110	173.260	73.280	32.408	4.632	8.44E-06
		SA	5.169	5.394	0.130	172.060	75.160	33.288	4.494	4.85E-20
		PSO	5.257	5.427	0.137	174.000	73.700	33.098	4.567	1.24E-11
		Greedy	3.295	3.549	0.204	201.200	1225.500	61.062	3.046	1.80E-68
		THACS	5.448	5.570	0.071	191.400	67.320	35.134	4.769	–
		ACS	5.324	5.501	0.112	189.920	81.920	35.669	4.670	3.63E-09
		IMMAS	5.337	5.532	0.114	190.800	69.500	35.750	4.682	1.03E-07
3	300	GA	5.316	5.492	0.086	187.620	63.740	35.295	4.656	5.71E-13
		SA	5.233	5.486	0.152	186.200	66.120	35.582	4.588	2.16E-13
		PSO	5.263	5.329	0.039	188.260	65.600	35.770	4.618	3.19E-26
		Greedy	3.370	3.900	0.324	225.260	1157.400	66.850	3.135	6.07E-44
		THACS	5.476	5.685	0.125	208.860	60.220	38.144	4.841	–
		ACS	5.373	5.513	0.101	210.000	67.480	39.084	4.764	1.69E-05
		IMMAS	5.402	5.569	0.131	208.200	65.180	38.543	4.781	4.70E-03
4	325	GA	5.347	5.483	0.072	207.260	56.920	38.765	4.736	1.44E-08
		SA	5.223	5.397	0.093	206.220	59.300	39.483	4.636	2.33E-19
		PSO	5.252	5.472	0.119	207.680	58.060	39.545	4.662	8.01E-15
		Greedy	3.371	3.879	0.304	245.620	1131.220	72.860	3.155	5.75E-51
		THACS	5.510	5.674	0.077	222.800	53.800	40.436	4.904	–
		ACS	5.424	5.622	0.129	224.880	62.520	41.459	4.840	1.12E-04
		IMMAS	5.464	5.651	0.128	223.620	58.600	40.930	4.869	3.17E-02
5	350	GA	5.390	5.540	0.121	220.240	50.900	40.861	4.802	6.44E-08
		SA	5.209	5.440	0.124	219.180	52.840	42.076	4.656	1.92E-24
		PSO	5.359	5.499	0.134	222.120	51.300	41.452	4.782	1.19E-09
		Greedy	3.443	3.773	0.174	268.700	1008.060	78.054	3.235	3.20E-67

Appendix D. The experimental results of the 3×4 sucker matrix configuration.

No.	Amount	Methods	e_n	e_{max}	*std*	$\bar{n}$	$\overline{N_c}$	t_w	e_t	p-value
		THACS	6.225	6.306	0.108	154.300	59.800	24.788	5.180	–
		ACS	6.090	6.265	0.111	152.420	71.780	25.029	5.076	1.54E-08
		IMMAS	6.110	6.256	0.116	154.900	64.900	25.353	5.103	1.48E-06
1	250	GA	6.010	6.164	0.112	154.120	57.660	25.645	5.029	4.17E-16
		SA	5.950	6.091	0.126	150.560	59.060	25.306	4.968	2.92E-20
		PSO	6.008	6.165	0.114	152.200	57.940	25.332	5.018	3.55E-16
		Greedy	4.029	5.564	0.594	170.120	766.880	42.224	3.602	2.62E-31
		THACS	6.076	6.228	0.085	169.500	52.780	27.897	5.152	–
		ACS	5.931	6.049	0.107	167.700	60.060	28.275	5.040	3.02E-11
		IMMAS	5.936	6.082	0.117	168.800	56.000	28.435	5.049	8.31E-10
2	275	GA	5.893	6.098	0.125	167.260	50.780	28.383	5.010	3.95E-13
		SA	5.823	5.965	0.107	165.100	52.800	28.354	4.950	7.30E-23
		PSO	5.866	6.010	0.119	165.220	51.820	28.164	4.982	1.49E-16
		Greedy	4.075	5.316	0.591	195.200	619.360	47.896	3.690	3.45E-29
		THACS	6.065	6.250	0.101	185.100	45.500	30.521	5.211	–
		ACS	5.919	6.102	0.078	184.200	56.460	31.119	5.100	2.36E-12
		IMMAS	5.904	6.115	0.093	183.300	51.700	31.047	5.085	6.60E-13
3	300	GA	5.863	6.012	0.098	185.660	46.000	31.666	5.063	5.16E-17
		SA	5.778	6.002	0.129	185.140	47.660	32.043	4.998	2.09E-21
		PSO	5.804	5.942	0.111	185.160	46.860	31.903	5.017	1.40E-21
		Greedy	3.529	4.558	0.410	219.000	578.700	62.051	3.266	1.07E-43
		THACS	6.073	6.243	0.105	198.700	41.560	32.718	5.268	–
		ACS	5.933	6.114	0.105	199.000	45.540	33.543	5.163	1.60E-09
		IMMAS	5.963	6.153	0.078	201.480	43.700	33.788	5.194	5.16E-08
4	325	GA	5.869	5.945	0.069	196.360	39.340	33.455	5.106	5.86E-19
		SA	5.769	5.942	0.084	195.160	38.360	33.829	5.026	1.85E-28
		PSO	5.840	5.953	0.082	197.220	39.980	33.771	5.087	2.61E-21
		Greedy	3.704	3.893	0.161	235.120	517.600	63.470	3.434	3.00E-84
		THACS	6.131	6.252	0.127	215.100	38.700	35.085	5.366	–
		ACS	5.967	6.224	0.129	216.220	43.740	36.234	5.244	5.29E-09
		IMMAS	5.995	6.243	0.121	215.400	40.760	35.927	5.263	3.22E-07
5	350	GA	5.883	6.124	0.143	213.160	37.180	36.233	5.170	7.56E-15
		SA	5.796	5.945	0.078	212.000	38.200	36.578	5.099	9.75E-27
		PSO	5.854	6.042	0.133	214.880	37.640	36.707	5.152	4.29E-18
		Greedy	3.591	4.142	0.255	257.200	482.620	71.632	3.356	1.42E-64

Appendix E. The experimental results of the 3×5 sucker matrix configuration.

No.	Amount	Methods	e_n	e_{max}	*std*	$\bar{n}$	$\overline{N_c}$	t_w	e_t	p-value
		THACS	6.318	6.424	0.110	150.100	41.080	23.759	5.219	–
		ACS	6.214	6.401	0.108	143.800	43.270	23.143	5.110	6.57E-06
		IMMAS	6.246	6.410	0.115	145.500	42.440	23.294	5.142	1.89E-03
1	250	GA	6.122	6.325	0.099	144.160	40.400	23.546	5.050	3.31E-15
		SA	5.912	6.125	0.123	143.260	41.000	24.233	4.901	1.55E-31
		PSO	6.016	6.245	0.130	143.880	40.760	23.916	4.976	7.16E-22
		Greedy	3.486	4.829	0.718	162.800	418.060	46.702	3.149	2.00E-32
		THACS	6.372	6.513	0.090	160.320	36.020	25.160	5.316	–
		ACS	6.253	6.455	0.138	159.400	37.960	25.493	5.228	1.97E-06
		IMMAS	6.284	6.435	0.139	163.240	36.780	25.977	5.270	3.19E-04
2	275	GA	6.191	6.351	0.099	159.260	35.660	25.725	5.183	1.01E-15
		SA	5.979	6.165	0.138	160.000	35.940	26.759	5.038	9.59E-29
		PSO	6.062	6.264	0.168	159.480	35.860	26.307	5.094	3.58E-18
		Greedy	3.484	4.936	0.682	187.900	382.260	53.932	3.188	1.05E-33
		THACS	6.299	6.410	0.099	177.300	32.940	28.149	5.349	–
		ACS	6.179	6.371	0.117	175.880	35.000	28.466	5.255	2.59E-07
		IMMAS	6.211	6.357	0.117	176.400	34.240	28.402	5.281	9.47E-05
3	300	GA	6.087	6.294	0.086	175.260	32.500	28.793	5.186	1.05E-19
		SA	5.877	6.105	0.123	174.200	33.060	29.640	5.029	1.20E-33
		PSO	5.960	6.156	0.144	175.000	32.800	29.362	5.093	1.56E-23
		Greedy	3.691	5.092	0.692	210.320	333.780	56.982	3.393	2.21E-31
		THACS	6.325	6.457	0.115	192.100	31.480	30.372	5.431	–
		ACS	6.226	6.439	0.129	189.400	33.480	30.421	5.347	1.01E-04
		IMMAS	6.253	6.435	0.124	191.100	32.620	30.560	5.374	3.22E-03
4	325	GA	6.108	6.245	0.072	188.440	30.880	30.854	5.256	1.65E-18
		SA	5.900	6.045	0.105	187.240	31.300	31.734	5.097	4.26E-35
		PSO	6.002	6.125	0.108	189.600	31.220	31.589	5.182	4.36E-26
		Greedy	3.626	4.325	0.392	227.300	319.280	62.679	3.359	2.50E-47
		THACS	6.217	6.431	0.102	211.400	25.400	34.001	5.420	–
		ACS	6.121	6.345	0.115	206.300	26.420	33.702	5.330	2.54E-05
		IMMAS	6.159	6.342	0.126	209.400	26.380	33.997	5.370	1.31E-02
5	350	GA	5.993	6.164	0.112	208.160	25.140	34.731	5.239	1.47E-17
		SA	5.841	6.095	0.114	209.820	25.540	35.920	5.128	1.52E-31
		PSO	5.928	6.137	0.152	210.120	25.460	35.446	5.195	1.89E-18
		Greedy	3.512	4.576	0.528	249.600	267.960	71.065	3.281	1.61E-38

Appendix F. The experimental results of the 3×6 sucker matrix configuration.

No.	Amount	Methods	e_n	e_{max}	*std*	$\bar{n}$	$\overline{N_c}$	t_w	e_t	p-value
		THACS	6.418	6.530	0.111	132.000	15.920	20.567	5.163	–
		ACS	6.315	6.517	0.111	131.960	16.560	20.896	5.096	1.13E-05
		IMMAS	6.347	6.523	0.117	131.800	16.140	20.764	5.116	2.45E-03
1	250	GA	6.314	6.523	0.106	131.920	15.800	20.892	5.095	6.22E-06
		SA	6.016	6.212	0.115	130.200	15.920	21.644	4.887	2.50E-32
		PSO	6.122	6.375	0.141	130.980	15.820	21.393	4.963	7.92E-20
		Greedy	4.181	4.671	0.467	146.280	190.020	34.985	3.658	1.11E-37
		THACS	6.288	6.393	0.089	145.800	13.940	23.186	5.173	–
		ACS	6.169	6.273	0.093	145.220	14.560	23.541	5.088	2.67E-09
		IMMAS	6.198	6.342	0.104	147.100	14.460	23.733	5.120	1.05E-05
2	275	GA	6.076	6.290	0.086	146.760	13.020	24.152	5.034	3.24E-21
		SA	5.898	6.113	0.135	146.460	13.720	24.832	4.909	2.93E-29
		PSO	5.940	6.151	0.152	147.020	13.040	24.752	4.941	4.00E-23
		Greedy	4.194	4.874	0.697	158.120	164.880	37.703	3.703	1.07E-26
		THACS	6.210	6.331	0.080	159.260	13.180	25.647	5.197	–
		ACS	6.111	6.247	0.096	159.660	13.760	26.125	5.130	2.00E-07
		IMMAS	6.149	6.325	0.113	161.120	13.420	26.205	5.163	2.49E-03
3	300	GA	5.962	6.059	0.099	160.220	11.820	26.874	5.027	2.16E-24
		SA	5.817	6.051	0.125	159.420	12.980	27.406	4.919	1.04E-31
		PSO	5.913	6.059	0.132	160.100	12.080	27.074	4.992	1.29E-22
		Greedy	3.512	4.576	0.528	184.700	141.540	52.587	3.207	7.38E-38
		THACS	6.428	6.530	0.095	171.400	12.080	26.666	5.413	–
		ACS	6.347	6.531	0.119	171.380	14.480	27.004	5.355	2.82E-04
		IMMAS	6.366	6.510	0.111	172.440	12.400	27.087	5.374	3.39E-03
4	325	GA	6.316	6.538	0.109	172.360	11.280	27.291	5.338	3.20E-07
		SA	6.027	6.331	0.141	170.060	12.220	28.214	5.120	1.28E-28
		PSO	6.146	6.413	0.133	171.620	11.800	27.922	5.213	1.19E-20
		Greedy	4.181	4.671	0.467	204.260	127.460	48.852	3.793	3.16E-37
		THACS	6.383	6.527	0.099	187.800	11.000	29.420	5.456	–
		ACS	6.277	6.493	0.140	185.440	11.440	29.545	5.368	3.31E-05
		IMMAS	6.290	6.495	0.148	186.620	11.240	29.669	5.383	3.97E-04
5	350	GA	6.204	6.425	0.122	184.260	9.800	29.701	5.310	2.54E-12
		SA	6.001	6.347	0.177	182.200	10.840	30.361	5.153	1.03E-21
		PSO	6.073	6.275	0.163	184.400	10.020	30.362	5.215	1.25E-18
		Greedy	4.078	5.541	0.760	222.060	115.940	54.447	3.735	6.75E-27