

A Hybrid Algorithm for the Partition Coloring Problem

Optional Subtitle

DIPLOMARBEIT

zur Erlangung des akademischen Grades

Diplom-Ingenieurin

im Rahmen des Studiums

Computational Intelligence

eingereicht von

Gilbert Fritz

Matrikelnummer 0827276

an der
Fakultät für Informatik der Technischen Universität Wien

Betreuung: Univ.Ass. Dipl.-Ing. Dr.techn. Dr. Bin Hu
Mitwirkung: Univ.-Prof. Dipl.-Ing. Dr.techn. Günther Raidl

Wien, 21.Oct.2013

(Unterschrift Verfasserin)

(Unterschrift Betreuung)

A Hybrid Algorithm for the Partition Coloring Problem

Optional Subtitle

MASTER'S THESIS

submitted in partial fulfillment of the requirements for the degree of

Diplom-Ingenieurin

in

Computational Intelligence

by

Gilbert Fritz

Registration Number 0827276

to the Faculty of Informatics
at the Vienna University of Technology

Advisor: Univ.Ass. Dipl.-Ing. Dr.techn. Dr. Bin Hu
Assistance: Univ.-Prof. Dipl.-Ing. Dr.techn. Günther Raidl

Vienna, 21.Oct.2013

(Signature of Author)

(Signature of Advisor)

Erklärung zur Verfassung der Arbeit

Gilbert Fritz
Schlosshofer Straße 49/18

Hiermit erkläre ich, dass ich diese Arbeit selbständig verfasst habe, dass ich die verwendeten Quellen und Hilfsmittel vollständig angegeben habe und dass ich die Stellen der Arbeit - einschließlich Tabellen, Karten und Abbildungen -, die anderen Werken oder dem Internet im Wortlaut oder dem Sinn nach entnommen sind, auf jeden Fall unter Angabe der Quelle als Entlehnung kenntlich gemacht habe.

(Ort, Datum)

(Unterschrift Verfasserin)

Acknowledgements

Optional acknowledgements may be inserted here.

Contents

1	Introduction	1
1.1	Motivation	1
1.2	Guide to the Thesis	1
2	Preliminaries	3
2.1	Graph Theory Definitions	3
2.2	Metaheuristics	3
3	Problem Definition	5
3.1	Partition Coloring Problem	5
3.2	Routing and Wavelength Assignment Problem	6
3.3	Complexity	6
4	Previous Works	7
4.1	Exact Approaches	7
4.2	Heuristical Approaches	7
5	Problem Solving Approach	9
5.1	Constructional Heuristics	9
5.2	Recoloring	9
5.3	Local Search	9
5.4	Variants	9
6	Computational Results	11
6.1	Implementation Details and Testing Environment	11
6.2	Instances	11
6.3	Results	12
7	Summary	37
7.1	Critical Reflection	37
7.2	Future Works	38
	Bibliography	39

CHAPTER 1

Introduction

1.1 Motivation

1.2 Guide to the Thesis

CHAPTER 2

Preliminaries

2.1 Graph Theory Definitions

2.2 Metaheuristics

Problem Definition

3.1 Partition Coloring Problem

Let $G = (V, E)$ be a non-directed graph and V partitioned into q subsets V_1, V_2, \dots, V_q , where $V_i \cap V_j = \emptyset, \forall i, j = 1, \dots, q, i \neq j$. We refer to V_1, V_2, \dots, V_q as the components of the partition. The PCP consists in finding a subset $V' \subset V$ such that $|V' \cap V_i| = 1, \forall i = 1, \dots, q$ (i.e., V' contains one node of each component V_i), and the chromatic number of the graph induced in G by V' is minimum.

Figure 3.1 shows an example of an instance with 10 nodes and a density of about 0.2.

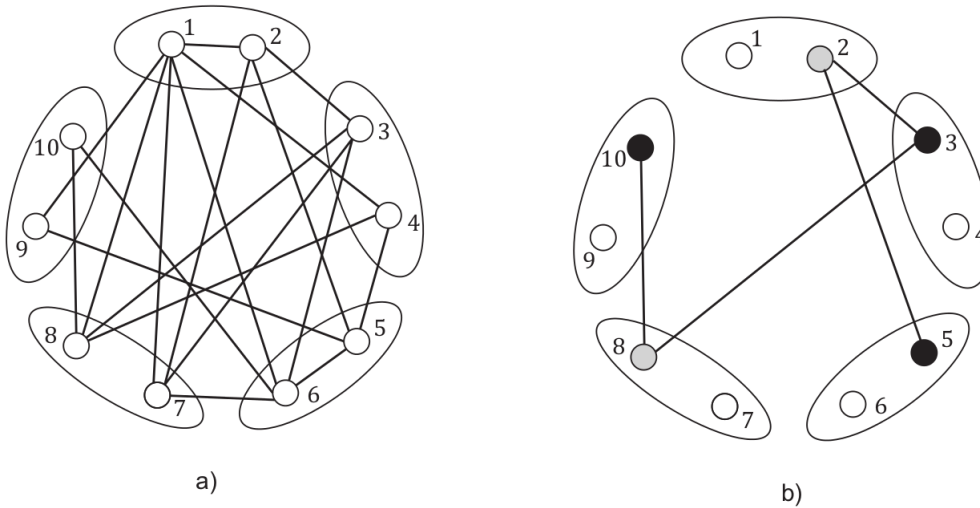


Figure 3.1: (a) Shows a problem instance and (b) its solution.

3.2 Routing and Wavelength Assignment Problem

where density is defined as the probability for each pair of nodes being connected by an edge. Note that when considering a real world instance of RWA, a density of 0.5 is very high and most instances will be of much sparser nature

3.3 Complexity

This problem is clearly a generalization of the graph colouring problem. Li and Simha [4] have shown that the decision version of PCP is NP-complete.

CHAPTER 4

Previous Works

4.1 Exact Approaches

4.2 Heuristical Approaches

Problem Solving Approach

5.1 Constructional Heuristics

5.2 Recoloring

Random

OneStepCD

ILP minimizing conflicts

ILP minimizing conflicting nodes

5.3 Local Search

5.4 Variants

Computational Results

This chapter provides information about the implementation, testing environment, instances used for evaluation and the computational results for different methods and parameters presented in chapter 5 are compared to each other and to results of [3–5].

6.1 Implementation Details and Testing Environment

The program has been implemented in Java and compiled with the JDK compiler version 1.7.0_25. For reasons of runtime comparability it has been designed to execute on a single thread, although the recoloring for each set of clusters of same color makes the program highly suitable to be processed in a parallel way. For the implementation of abstract data structures no other libraries than the ones provided by the JDK have been used. For solving the ILPs described in 5.4, ILOG CPLEX version 12.5 has been used, which is by now one of the fastest CP solvers available [1]. It is written in C++, provides facades to Java, Python, .NET, Matlab, Excel and supports comfortable usage of integer variables and a wide set of constraints and solving strategies. All tests have been performed on a Pentium i5 DualCore, 2.5 GHz, 8GB RAM, with Linux Mint 14 and OpenJDK Runtime Environment (IcedTea 2.3.9) installed.

6.2 Instances

Instances of different size, nodes per cluster ratio and density have been evaluated. Generated randomly and used by the authors of [3], the instances have also been evaluated in [6] and [?]. For reasons of better comparability to previous works, instances have been pooled to sets of same size respectively density. Furthermore four larger instances with constant density of 0.5 and different sizes of 500, 1000, 1500 and 2000 nodes provided by the authors of [5] have been evaluated and compared.

6.3 Results

In the following section preliminarily and final results as well as comparison to results of previous works are presented. There have been preceding tests to select the most competitive ranges of parameters used in the tables.

Conflicting Nodes

As an intermediate result the numbers of conflicting nodes per each recoloring produced by the different recoloring algorithms have been recorded and compared to each other. Since for these experiments a constant length has been used for the tabu list, *HYBRID-PCP* is deterministic except the case when random recoloring is used. Therefore for random recoloring the average of ten runs per instance and recoloring has been calculated.

In tables 6.1 and 6.2 the results for sets of different size respectively density are presented. Each set contains five instances. Table 6.3 presents the results for the four larger instances. It can be seen that a large number of nodes and as well as a low density lead to a high amount of conflicts per recoloring. The difference between the results for *RANDOM* and *ILP2* grows to a factor of over 7.5 on the larger instances.

Instance set		Random (10 runs/inst)	OneStepCD	ILP1	ILP2
nodes	density	<i>cnodes/recoloring</i>	<i>cnodes/recoloring</i>	<i>cnodes/recoloring</i>	<i>cnodes/recoloring</i>
20	0.5	3.69	2.25	1.60	1.36
40	0.5	7.33	3.85	3.21	2.29
60	0.5	10.21	4.99	4.21	2.83
70	0.5	11.30	5.84	4.56	3.27
80	0.5	12.69	6.04	4.97	3.41
90	0.5	12.32	5.93	4.64	3.38
100	0.5	14.91	7.16	5.23	3.92
120	0.5	15.53	6.44	5.07	3.38

Table 6.1: Sets of different size containing five instances each. *cnodes/recoloring* denotes the average amount of conflicting nodes per recoloring.

Instance set		Random (10 runs/inst)	OneStepCD	ILP1	ILP2
nodes	density	<i>cnodes/recoloring</i>	<i>cnodes/recoloring</i>	<i>cnodes/recoloring</i>	<i>cnodes/recoloring</i>
90	0.1	15.71	9.50	6.61	5.65
90	0.2	16.70	7.99	6.36	4.87
90	0.3	15.94	7.60	5.48	4.03
90	0.4	14.73	6.16	4.75	3.41
90	0.5	13.51	5.93	4.94	3.43
90	0.6	11.78	5.20	4.39	2.84
90	0.7	9.60	4.61	3.90	2.44
90	0.8	7.70	3.66	3.04	2.05
90	0.9	5.56	2.69	2.34	1.74

Table 6.2: Sets of different density containing five instances each.

Instance set		Random (10 runs/inst)	OneStepCD	ILP1	ILP2
nodes	density	<i>cnodes/recoloring</i>	<i>cnodes/recoloring</i>	<i>cnodes/recoloring</i>	<i>cnodes/recoloring</i>
500	0.5	35.13	7.89	7.88	5.02
1000	0.5	39.87	9.15	7.74	5.15
1500	0.5	44.67	11.52	8.12	6.02
2000	0.5	46.81	12.29	4.75	6.42

Table 6.3: Evaluation of the four larger instances. *ILP2* produces about 7.5 times less conflicting nodes than *RANDOM*.

Final Results

For each set of instances experiments with various ranges of tabu list lengths as well as various boundaries for the maximum number of iterations have been performed. The size of the tabu list for each insertion is a random number between the lower and upper bound given as *TabuTenure*, where C' is the tentative number of colors. Because of that indeterminism 10 runs per instance have been performed. The maximum number of iterations used as stopping criterion is set as $maxIter = q * (C') * F_{end}$, where q is the amount of clusters. Tables 6.4 to 6.20 show the results of the instances provided in [3]. In tables 6.21 to 6.24 results of the large instances are shown, where the values of the parameters *TabuTenure* and F_{end} have been chosen similar to the ones used in [5]. The following tables are labeled like the names of each instance, indicating its size and density, e.g. *pcpn90p1* indicates an instance of 90 nodes and density 0.1.

The final results do not exhibit an improvement similar to the preliminary results or any significant improvement at all. Especially on larger instances the dramatic differences between the runtimes of the exact and non-exact methods becomes visible. For most instances except the four large ones a *TabuTenure* of $U[1.0C', 4.0C']$ and $U[0.0C', 5.0C']$ has shown to lead to best results. For the larger instances, a *TabuTenure* of $U[0.0C', 0.5C']$ fits best, which approves the results in [5].

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	3.0	0.000	0.047	3.0	0.000	0.001	3.0	0.000	0.040	3.0	0.000	0.224
	$U[0.5C', 1.0C']$	3.0	0.000	0.016	3.0	0.000	0.001	3.0	0.000	0.029	3.0	0.000	0.211
	$U[1.0C', 4.0C']$	3.0	0.000	0.010	3.0	0.000	0.001	3.0	0.000	0.033	3.0	0.000	0.197
	$U[0.0C', 5.0C']$	3.0	0.000	0.006	3.0	0.000	0.001	3.0	0.000	0.028	3.0	0.000	0.204
	$U[5.0C', 10.0C']$	3.0	0.000	0.005	3.0	0.000	0.001	3.0	0.000	0.023	3.0	0.000	0.224
	$U[10.0C', 20.0C']$	3.0	0.000	0.004	3.0	0.000	0.001	3.0	0.000	0.025	3.0	0.000	0.188
10	$U[0.0C', 0.5C']$	2.9	0.050	0.010	3.0	0.000	0.004	3.0	0.000	0.029	3.0	0.000	0.204
	$U[0.5C', 1.0C']$	2.9	0.050	0.007	2.9	0.050	0.005	3.0	0.000	0.030	2.9	0.050	0.186
	$U[1.0C', 4.0C']$	2.9	0.050	0.005	2.9	0.050	0.005	3.0	0.000	0.030	3.0	0.000	0.198
	$U[0.0C', 5.0C']$	3.0	0.000	0.005	2.9	0.050	0.005	3.0	0.000	0.029	2.8	0.000	0.183
	$U[5.0C', 10.0C']$	3.0	0.000	0.006	2.9	0.050	0.005	3.0	0.000	0.030	2.9	0.050	0.198
	$U[10.0C', 20.0C']$	3.0	0.000	0.005	2.9	0.050	0.005	3.0	0.000	0.027	3.0	0.000	0.209
20	$U[0.0C', 0.5C']$	3.0	0.000	0.008	2.9	0.050	0.009	2.9	0.050	0.034	3.0	0.000	0.213
	$U[0.5C', 1.0C']$	3.0	0.000	0.008	2.9	0.050	0.008	3.0	0.000	0.031	3.0	0.000	0.194
	$U[1.0C', 4.0C']$	3.0	0.000	0.008	3.0	0.000	0.009	3.0	0.000	0.030	3.0	0.000	0.240
	$U[0.0C', 5.0C']$	3.0	0.000	0.008	3.0	0.000	0.008	2.9	0.050	0.030	3.0	0.000	0.215
	$U[5.0C', 10.0C']$	3.0	0.000	0.008	2.8	0.000	0.009	3.0	0.000	0.032	2.9	0.050	0.214
	$U[10.0C', 20.0C']$	2.9	0.050	0.009	3.0	0.000	0.008	3.0	0.000	0.031	3.0	0.000	0.202
50	$U[0.0C', 0.5C']$	3.0	0.000	0.017	3.0	0.000	0.018	3.0	0.000	0.040	3.0	0.000	0.200
	$U[0.5C', 1.0C']$	3.0	0.000	0.021	3.0	0.000	0.018	2.9	0.050	0.042	3.0	0.000	0.213
	$U[1.0C', 4.0C']$	3.0	0.000	0.018	3.0	0.000	0.018	3.0	0.000	0.038	2.9	0.050	0.225
	$U[0.0C', 5.0C']$	2.9	0.050	0.019	3.0	0.000	0.018	2.9	0.050	0.041	3.0	0.000	0.235
	$U[5.0C', 10.0C']$	3.0	0.000	0.017	3.0	0.000	0.017	2.9	0.050	0.040	3.0	0.000	0.201
	$U[10.0C', 20.0C']$	2.8	0.000	0.021	2.9	0.050	0.020	2.9	0.050	0.041	2.9	0.050	0.223

Table 6.4: Results for a set of 5 instances of size 90 and density 0.1

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	4.0	0.000	0.007	3.9	0.050	0.004	3.8	0.000	0.070	4.0	0.000	0.377
	$U[0.5C', 1.0C']$	4.0	0.000	0.004	3.9	0.050	0.004	3.6	0.800	0.062	4.0	0.000	0.354
	$U[1.0C', 4.0C']$	4.0	0.000	0.003	3.9	0.050	0.004	3.9	0.050	0.064	4.0	0.000	0.357
	$U[0.0C', 5.0C']$	3.9	0.050	0.003	4.0	0.000	0.003	4.0	0.000	0.064	3.9	0.050	0.373
	$U[5.0C', 10.0C']$	4.0	0.000	0.003	3.9	0.050	0.004	4.0	0.000	0.067	4.0	0.000	0.354
	$U[10.0C', 20.0C']$	3.9	0.050	0.003	4.0	0.000	0.003	3.9	0.050	0.064	4.0	0.000	0.349
10	$U[0.0C', 0.5C']$	3.9	0.050	0.015	3.8	0.000	0.016	3.9	0.050	0.075	3.9	0.050	0.364
	$U[0.5C', 1.0C']$	3.9	0.050	0.014	3.9	0.050	0.015	3.8	0.000	0.079	4.0	0.000	0.373
	$U[1.0C', 4.0C']$	3.9	0.050	0.014	3.9	0.050	0.014	3.8	0.000	0.078	3.8	0.000	0.445
	$U[0.0C', 5.0C']$	3.9	0.050	0.015	3.8	0.000	0.015	3.8	0.000	0.080	3.8	0.000	0.439
	$U[5.0C', 10.0C']$	3.9	0.050	0.015	3.8	0.000	0.015	3.8	0.000	0.080	3.8	0.000	0.446
	$U[10.0C', 20.0C']$	3.8	0.000	0.017	3.9	0.050	0.016	3.8	0.000	0.079	3.8	0.000	0.455
20	$U[0.0C', 0.5C']$	4.0	0.000	0.025	3.8	0.000	0.028	3.9	0.050	0.091	3.8	0.000	0.436
	$U[0.5C', 1.0C']$	3.8	0.000	0.028	3.8	0.000	0.027	3.9	0.050	0.088	3.9	0.050	0.412
	$U[1.0C', 4.0C']$	3.9	0.050	0.028	3.9	0.050	0.027	3.8	0.000	0.091	3.8	0.000	0.417
	$U[0.0C', 5.0C']$	3.8	0.000	0.029	3.9	0.050	0.027	3.8	0.000	0.087	3.9	0.050	0.438
	$U[5.0C', 10.0C']$	3.8	0.000	0.028	3.8	0.000	0.028	3.8	0.000	0.090	3.8	0.000	0.460
	$U[10.0C', 20.0C']$	3.8	0.000	0.028	3.8	0.000	0.028	3.8	0.000	0.091	3.8	0.000	0.477
50	$U[0.0C', 0.5C']$	3.8	0.000	0.062	4.0	0.000	0.058	3.8	0.000	0.130	3.9	0.050	0.438
	$U[0.5C', 1.0C']$	3.8	0.000	0.066	3.9	0.050	0.059	3.9	0.050	0.117	3.9	0.050	0.459
	$U[1.0C', 4.0C']$	3.8	0.000	0.064	3.9	0.050	0.059	3.9	0.050	0.123	3.9	0.050	0.439
	$U[0.0C', 5.0C']$	3.9	0.050	0.063	3.8	0.000	0.068	3.8	0.000	0.123	3.8	0.000	0.459
	$U[5.0C', 10.0C']$	3.8	0.000	0.066	3.8	0.000	0.065	3.8	0.000	0.132	3.8	0.000	0.431
	$U[10.0C', 20.0C']$	3.8	0.000	0.071	3.8	0.000	0.067	3.8	0.000	0.128	3.8	0.000	0.445

Table 6.5: Results for a set of 5 instances of size 90 and density 0.2

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	5.0	0.000	0.007	5.0	0.000	0.005	5.0	0.000	0.105	5.0	0.000	0.424
	$U[0.5C', 1.0C']$	5.0	0.000	0.005	5.0	0.000	0.006	5.0	0.000	0.098	5.0	0.000	0.430
	$U[1.0C', 4.0C']$	5.0	0.000	0.005	5.0	0.000	0.005	5.0	0.000	0.099	5.0	0.000	0.426
	$U[0.0C', 5.0C']$	5.0	0.000	0.006	5.0	0.000	0.007	5.0	0.000	0.095	5.0	0.000	0.417
	$U[5.0C', 10.0C']$	5.0	0.000	0.005	5.0	0.000	0.005	5.0	0.000	0.097	5.0	0.000	0.430
	$U[10.0C', 20.0C']$	5.0	0.000	0.005	5.0	0.000	0.005	5.0	0.000	0.091	5.0	0.000	0.373
10	$U[0.0C', 0.5C']$	5.0	0.000	0.028	5.0	0.000	0.029	5.0	0.000	0.115	5.0	0.000	0.436
	$U[0.5C', 1.0C']$	5.0	0.000	0.029	5.0	0.000	0.030	5.0	0.000	0.119	5.0	0.000	0.465
	$U[1.0C', 4.0C']$	5.0	0.000	0.029	5.0	0.000	0.029	5.0	0.000	0.115	5.0	0.000	0.436
	$U[0.0C', 5.0C']$	5.0	0.000	0.029	5.0	0.000	0.029	5.0	0.000	0.115	5.0	0.000	0.449
	$U[5.0C', 10.0C']$	5.0	0.000	0.029	5.0	0.000	0.029	5.0	0.000	0.126	5.0	0.000	0.400
	$U[10.0C', 20.0C']$	5.0	0.000	0.030	5.0	0.000	0.030	5.0	0.000	0.118	5.0	0.000	0.378
20	$U[0.0C', 0.5C']$	5.0	0.000	0.052	5.0	0.000	0.055	5.0	0.000	0.138	5.0	0.000	0.436
	$U[0.5C', 1.0C']$	5.0	0.000	0.052	5.0	0.000	0.053	5.0	0.000	0.141	5.0	0.000	0.431
	$U[1.0C', 4.0C']$	5.0	0.000	0.055	5.0	0.000	0.055	5.0	0.000	0.137	5.0	0.000	0.439
	$U[0.0C', 5.0C']$	5.0	0.000	0.055	5.0	0.000	0.055	5.0	0.000	0.149	5.0	0.000	0.435
	$U[5.0C', 10.0C']$	5.0	0.000	0.055	5.0	0.000	0.055	5.0	0.000	0.143	5.0	0.000	0.515
	$U[10.0C', 20.0C']$	5.0	0.000	0.056	5.0	0.000	0.059	5.0	0.000	0.150	5.0	0.000	0.447
50	$U[0.0C', 0.5C']$	5.0	0.000	0.127	5.0	0.000	0.126	5.0	0.000	0.205	5.0	0.000	0.513
	$U[0.5C', 1.0C']$	5.0	0.000	0.125	5.0	0.000	0.128	5.0	0.000	0.212	5.0	0.000	0.525
	$U[1.0C', 4.0C']$	5.0	0.000	0.128	5.0	0.000	0.129	5.0	0.000	0.217	5.0	0.000	0.526
	$U[0.0C', 5.0C']$	5.0	0.000	0.128	5.0	0.000	0.133	5.0	0.000	0.215	5.0	0.000	0.481
	$U[5.0C', 10.0C']$	5.0	0.000	0.136	5.0	0.000	0.131	5.0	0.000	0.223	5.0	0.000	0.538
	$U[10.0C', 20.0C']$	5.0	0.000	0.139	5.0	0.000	0.139	5.0	0.000	0.223	5.0	0.000	0.532

Table 6.6: Results for a set of 5 instances of size 90 and density 0.3

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	6.0	0.000	0.009	6.0	0.000	0.008	6.0	0.000	0.169	6.0	0.000	0.474
	$U[0.5C', 1.0C']$	6.0	0.000	0.010	6.0	0.000	0.009	6.0	0.000	0.167	6.0	0.000	0.492
	$U[1.0C', 4.0C']$	6.0	0.000	0.009	6.0	0.000	0.008	6.0	0.000	0.168	6.0	0.000	0.484
	$U[0.0C', 5.0C']$	6.0	0.000	0.008	6.0	0.000	0.008	6.0	0.000	0.164	6.0	0.000	0.467
	$U[5.0C', 10.0C']$	6.0	0.000	0.009	6.0	0.000	0.009	6.1	0.050	0.147	6.0	0.000	0.503
	$U[10.0C', 20.0C']$	6.0	0.000	0.009	6.0	0.000	0.009	6.0	0.000	0.159	6.0	0.000	0.474
10	$U[0.0C', 0.5C']$	6.0	0.000	0.054	6.0	0.000	0.054	6.0	0.000	0.200	6.0	0.000	0.536
	$U[0.5C', 1.0C']$	6.0	0.000	0.052	6.0	0.000	0.050	6.0	0.000	0.196	6.0	0.000	0.512
	$U[1.0C', 4.0C']$	6.0	0.000	0.052	6.0	0.000	0.052	6.0	0.000	0.204	6.0	0.000	0.534
	$U[0.0C', 5.0C']$	6.0	0.000	0.053	6.0	0.000	0.052	6.0	0.000	0.196	6.0	0.000	0.523
	$U[5.0C', 10.0C']$	6.0	0.000	0.053	6.0	0.000	0.055	6.0	0.000	0.185	6.0	0.000	0.526
	$U[10.0C', 20.0C']$	6.0	0.000	0.055	6.0	0.000	0.054	6.0	0.000	0.193	6.0	0.000	0.519
20	$U[0.0C', 0.5C']$	6.0	0.000	0.099	6.0	0.000	0.098	6.0	0.000	0.247	6.0	0.000	0.546
	$U[0.5C', 1.0C']$	6.0	0.000	0.097	6.0	0.000	0.095	6.0	0.000	0.243	6.0	0.000	0.562
	$U[1.0C', 4.0C']$	6.0	0.000	0.100	6.0	0.000	0.102	6.0	0.000	0.243	6.0	0.000	0.578
	$U[0.0C', 5.0C']$	6.0	0.000	0.100	6.0	0.000	0.101	6.0	0.000	0.247	6.0	0.000	0.567
	$U[5.0C', 10.0C']$	6.0	0.000	0.101	6.0	0.000	0.101	6.0	0.000	0.250	6.0	0.000	0.578
	$U[10.0C', 20.0C']$	6.0	0.000	0.103	6.0	0.000	0.103	6.0	0.000	0.252	6.0	0.000	0.605
50	$U[0.0C', 0.5C']$	6.0	0.000	0.233	6.0	0.000	0.233	6.0	0.000	0.396	6.0	0.000	0.722
	$U[0.5C', 1.0C']$	6.0	0.000	0.238	6.0	0.000	0.230	6.0	0.000	0.384	6.0	0.000	0.706
	$U[1.0C', 4.0C']$	6.0	0.000	0.240	6.0	0.000	0.237	6.0	0.000	0.384	6.0	0.000	0.714
	$U[0.0C', 5.0C']$	6.0	0.000	0.244	6.0	0.000	0.243	6.0	0.000	0.384	6.0	0.000	0.725
	$U[5.0C', 10.0C']$	6.0	0.000	0.247	6.0	0.000	0.245	6.0	0.000	0.393	6.0	0.000	0.689
	$U[10.0C', 20.0C']$	6.0	0.000	0.256	6.0	0.000	0.254	6.0	0.000	0.395	6.0	0.000	0.721

Table 6.7: Results for a set of 5 instances of size 90 and density 0.4

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	7.2	0.000	0.015	7.2	0.000	0.014	7.1	0.050	0.216	7.2	0.000	0.617
	$U[0.5C', 1.0C']$	7.2	0.000	0.017	7.2	0.100	0.014	7.2	0.000	0.204	7.4	0.000	0.560
	$U[1.0C', 4.0C']$	7.0	0.000	0.014	7.1	0.050	0.015	7.2	0.100	0.199	7.1	0.050	0.632
	$U[0.0C', 5.0C']$	7.1	0.050	0.014	7.2	0.000	0.014	7.1	0.050	0.211	7.1	0.050	0.606
	$U[5.0C', 10.0C']$	7.3	0.050	0.014	7.0	0.000	0.016	7.2	0.100	0.194	7.2	0.000	0.583
	$U[10.0C', 20.0C']$	7.2	0.100	0.015	7.5	0.050	0.014	7.4	0.100	0.193	7.4	0.100	0.567
10	$U[0.0C', 0.5C']$	7.0	0.000	0.098	7.0	0.000	0.095	7.1	0.050	0.285	7.1	0.050	0.700
	$U[0.5C', 1.0C']$	7.0	0.000	0.108	7.2	0.000	0.086	7.0	0.000	0.278	7.1	0.050	0.709
	$U[1.0C', 4.0C']$	7.0	0.000	0.089	7.0	0.000	0.090	7.0	0.000	0.288	7.0	0.000	0.719
	$U[0.0C', 5.0C']$	7.0	0.000	0.088	7.0	0.000	0.089	7.0	0.000	0.300	7.0	0.000	0.716
	$U[5.0C', 10.0C']$	7.0	0.000	0.096	7.0	0.000	0.094	7.0	0.000	0.299	7.0	0.000	0.719
	$U[10.0C', 20.0C']$	7.1	0.050	0.097	7.1	0.050	0.097	7.0	0.000	0.313	7.0	0.000	0.709
20	$U[0.0C', 0.5C']$	7.1	0.050	0.191	7.1	0.050	0.185	7.0	0.000	0.375	7.2	0.000	0.755
	$U[0.5C', 1.0C']$	7.1	0.050	0.193	7.0	0.000	0.178	7.1	0.050	0.363	7.1	0.050	0.789
	$U[1.0C', 4.0C']$	7.0	0.000	0.172	7.0	0.000	0.173	7.0	0.000	0.367	7.0	0.000	0.763
	$U[0.0C', 5.0C']$	7.0	0.000	0.172	7.0	0.000	0.174	7.0	0.000	0.369	7.0	0.000	0.787
	$U[5.0C', 10.0C']$	7.0	0.000	0.178	7.0	0.000	0.182	7.0	0.000	0.379	7.0	0.000	0.796
	$U[10.0C', 20.0C']$	7.0	0.000	0.205	7.1	0.050	0.185	7.1	0.050	0.386	7.1	0.050	0.792
50	$U[0.0C', 0.5C']$	7.0	0.000	0.433	7.1	0.050	0.409	7.1	0.050	0.617	7.0	0.000	1.071
	$U[0.5C', 1.0C']$	7.2	0.000	0.436	7.0	0.000	0.459	7.2	0.000	0.577	7.0	0.000	1.073
	$U[1.0C', 4.0C']$	7.0	0.000	0.412	7.0	0.000	0.418	7.0	0.000	0.597	7.0	0.000	1.015
	$U[0.0C', 5.0C']$	7.0	0.000	0.408	7.0	0.000	0.419	7.0	0.000	0.600	7.0	0.000	1.018
	$U[5.0C', 10.0C']$	7.0	0.000	0.426	7.0	0.000	0.428	7.0	0.000	0.618	7.0	0.000	1.023
	$U[10.0C', 20.0C']$	7.0	0.000	0.478	7.0	0.000	0.442	7.0	0.000	0.681	7.0	0.000	1.039

Table 6.8: Results for a set of 5 instances of size 90 and density 0.5

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	8.8	0.100	0.022	9.0	0.000	0.021	8.8	0.100	0.264	8.8	0.100	0.729
	$U[0.5C', 1.0C']$	8.7	0.050	0.021	8.7	0.050	0.021	8.8	0.100	0.253	8.7	0.050	0.739
	$U[1.0C', 4.0C']$	8.7	0.050	0.020	8.6	0.100	0.022	8.7	0.050	0.268	8.5	0.150	0.774
	$U[0.0C', 5.0C']$	8.6	0.200	0.022	8.7	0.050	0.020	8.7	0.150	0.272	8.9	0.050	0.697
	$U[5.0C', 10.0C']$	8.8	0.100	0.021	8.8	0.100	0.021	8.7	0.050	0.256	8.9	0.050	0.708
	$U[10.0C', 20.0C']$	8.9	0.050	0.022	9.0	0.000	0.020	8.9	0.050	0.245	9.0	0.000	0.679
10	$U[0.0C', 0.5C']$	8.6	0.100	0.160	8.8	0.100	0.146	8.6	0.100	0.392	8.5	0.050	0.943
	$U[0.5C', 1.0C']$	8.7	0.050	0.144	8.4	0.100	0.157	8.5	0.150	0.422	8.6	0.100	0.891
	$U[1.0C', 4.0C']$	8.2	0.000	0.162	8.3	0.050	0.169	8.2	0.000	0.429	8.3	0.050	0.972
	$U[0.0C', 5.0C']$	8.2	0.000	0.171	8.2	0.000	0.148	8.2	0.000	0.445	8.3	0.050	0.955
	$U[5.0C', 10.0C']$	8.4	0.100	0.187	8.4	0.100	0.169	8.5	0.050	0.422	8.6	0.100	0.916
	$U[10.0C', 20.0C']$	8.8	0.000	0.158	8.8	0.000	0.159	8.7	0.050	0.400	8.5	0.050	0.928
20	$U[0.0C', 0.5C']$	8.8	0.100	0.297	8.8	0.100	0.287	8.6	0.100	0.552	8.6	0.000	1.053
	$U[0.5C', 1.0C']$	8.6	0.000	0.302	8.5	0.050	0.297	8.5	0.050	0.556	8.8	0.100	0.954
	$U[1.0C', 4.0C']$	8.2	0.000	0.306	8.2	0.000	0.307	8.2	0.000	0.567	8.2	0.000	1.137
	$U[0.0C', 5.0C']$	8.2	0.000	0.305	8.3	0.050	0.300	8.2	0.000	0.559	8.2	0.000	1.115
	$U[5.0C', 10.0C']$	8.3	0.050	0.325	8.3	0.050	0.326	8.2	0.000	0.600	8.4	0.100	1.110
	$U[10.0C', 20.0C']$	8.6	0.000	0.313	8.5	0.050	0.324	8.4	0.000	0.588	8.7	0.050	1.046
50	$U[0.0C', 0.5C']$	8.8	0.000	0.728	8.8	0.100	0.682	8.7	0.050	0.980	8.8	0.100	1.377
	$U[0.5C', 1.0C']$	8.6	0.100	0.768	8.6	0.100	0.684	8.7	0.050	0.892	8.6	0.100	1.436
	$U[1.0C', 4.0C']$	8.2	0.000	0.690	8.2	0.000	0.710	8.2	0.000	0.951	8.2	0.000	1.507
	$U[0.0C', 5.0C']$	8.2	0.000	0.716	8.2	0.000	0.757	8.2	0.000	0.984	8.2	0.000	1.526
	$U[5.0C', 10.0C']$	8.3	0.050	0.745	8.2	0.000	0.833	8.2	0.000	1.056	8.2	0.000	1.630
	$U[10.0C', 20.0C']$	8.4	0.100	0.860	8.4	0.100	0.797	8.3	0.050	1.102	8.5	0.050	1.560

Table 6.9: Results for a set of 5 instances of size 90 and density 0.6

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	10.6	0.100	0.037	10.2	0.100	0.034	10.5	0.050	0.301	10.4	0.200	0.865
	$U[0.5C', 1.0C']$	10.2	0.100	0.037	10.5	0.050	0.032	10.4	0.100	0.310	10.2	0.000	0.906
	$U[1.0C', 4.0C']$	10.1	0.050	0.038	10.1	0.050	0.034	10.3	0.050	0.340	10.1	0.050	0.927
	$U[0.0C', 5.0C']$	10.0	0.000	0.037	10.1	0.050	0.031	10.4	0.100	0.317	10.1	0.050	0.904
	$U[5.0C', 10.0C']$	10.4	0.100	0.034	10.5	0.150	0.034	10.2	0.100	0.328	10.2	0.100	0.921
	$U[10.0C', 20.0C']$	10.6	0.100	0.035	10.5	0.050	0.034	10.8	0.100	0.287	10.5	0.050	0.809
10	$U[0.0C', 0.5C']$	10.4	0.100	0.270	10.4	0.200	0.265	10.8	0.100	0.462	10.5	0.150	1.070
	$U[0.5C', 1.0C']$	10.0	0.000	0.309	10.0	0.000	0.264	10.2	0.000	0.556	10.2	0.100	1.113
	$U[1.0C', 4.0C']$	10.0	0.000	0.233	10.0	0.000	0.231	10.0	0.000	0.523	10.0	0.000	1.120
	$U[0.0C', 5.0C']$	10.0	0.000	0.229	10.0	0.000	0.230	10.0	0.000	0.536	10.0	0.000	1.129
	$U[5.0C', 10.0C']$	10.0	0.000	0.248	10.0	0.000	0.241	10.0	0.000	0.528	10.0	0.000	1.139
	$U[10.0C', 20.0C']$	10.0	0.000	0.311	10.0	0.000	0.300	10.0	0.000	0.588	10.0	0.000	1.230
20	$U[0.0C', 0.5C']$	10.5	0.050	0.502	10.4	0.100	0.527	10.5	0.250	0.821	10.6	0.100	1.237
	$U[0.5C', 1.0C']$	10.0	0.000	0.462	10.1	0.050	0.517	10.2	0.100	0.805	10.0	0.000	1.464
	$U[1.0C', 4.0C']$	10.0	0.000	0.445	10.0	0.000	0.446	10.0	0.000	0.726	10.0	0.000	1.336
	$U[0.0C', 5.0C']$	10.0	0.000	0.446	10.0	0.000	0.443	10.0	0.000	0.741	10.0	0.000	1.338
	$U[5.0C', 10.0C']$	10.0	0.000	0.471	10.0	0.000	0.467	10.0	0.000	0.782	10.0	0.000	1.357
	$U[10.0C', 20.0C']$	10.0	0.000	0.493	10.0	0.000	0.532	10.0	0.000	0.824	10.0	0.000	1.432
50	$U[0.0C', 0.5C']$	10.4	0.100	1.183	10.6	0.100	1.099	10.5	0.050	1.501	10.5	0.150	2.083
	$U[0.5C', 1.0C']$	10.1	0.050	1.215	10.1	0.050	1.338	10.2	0.000	1.554	10.0	0.000	2.200
	$U[1.0C', 4.0C']$	10.0	0.000	1.077	10.0	0.000	1.098	10.0	0.000	1.377	10.0	0.000	1.973
	$U[0.0C', 5.0C']$	10.0	0.000	1.078	10.0	0.000	1.086	10.0	0.000	1.403	10.0	0.000	1.990
	$U[5.0C', 10.0C']$	10.0	0.000	1.135	10.0	0.000	1.135	10.0	0.000	1.428	10.0	0.000	2.022
	$U[10.0C', 20.0C']$	10.0	0.000	1.197	10.0	0.000	1.193	10.0	0.000	1.471	10.0	0.000	2.066

Table 6.10: Results for a set of 5 instances of size 90 and density 0.7

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	12.6	0.100	0.058	12.8	0.000	0.056	13.0	0.000	0.464	13.1	0.150	1.040
	$U[0.5C', 1.0C']$	12.7	0.050	0.046	12.6	0.000	0.052	12.9	0.050	0.442	12.8	0.000	1.106
	$U[1.0C', 4.0C']$	12.6	0.100	0.049	12.5	0.050	0.048	12.7	0.050	0.467	12.7	0.050	1.109
	$U[0.0C', 5.0C']$	12.5	0.150	0.051	12.8	0.000	0.046	12.7	0.050	0.449	12.6	0.100	1.144
	$U[5.0C', 10.0C']$	12.7	0.050	0.051	12.5	0.050	0.058	12.6	0.100	0.457	12.8	0.000	1.100
	$U[10.0C', 20.0C']$	12.8	0.000	0.050	12.8	0.000	0.051	12.8	0.000	0.429	12.7	0.050	1.119
10	$U[0.0C', 0.5C']$	12.7	0.150	0.491	12.9	0.050	0.443	13.1	0.050	0.752	12.9	0.250	1.450
	$U[0.5C', 1.0C']$	12.6	0.100	0.410	12.4	0.100	0.440	12.5	0.050	0.819	12.6	0.100	1.490
	$U[1.0C', 4.0C']$	12.2	0.000	0.408	12.0	0.000	0.426	12.0	0.000	0.893	12.3	0.050	1.543
	$U[0.0C', 5.0C']$	12.1	0.050	0.390	12.1	0.050	0.429	12.0	0.000	0.903	12.1	0.050	1.600
	$U[5.0C', 10.0C']$	12.2	0.000	0.451	12.3	0.050	0.452	12.3	0.050	0.862	12.3	0.050	1.549
	$U[10.0C', 20.0C']$	12.5	0.050	0.437	12.4	0.100	0.459	12.5	0.150	0.852	12.5	0.050	1.546
20	$U[0.0C', 0.5C']$	12.9	0.050	0.750	12.9	0.050	0.907	12.8	0.100	1.173	12.9	0.050	1.885
	$U[0.5C', 1.0C']$	12.4	0.100	0.817	12.5	0.050	0.769	12.5	0.150	1.242	12.5	0.050	1.935
	$U[1.0C', 4.0C']$	12.0	0.000	0.770	12.0	0.000	0.918	12.0	0.000	1.271	12.0	0.000	2.063
	$U[0.0C', 5.0C']$	12.0	0.000	0.826	12.1	0.050	0.838	12.0	0.000	1.211	12.1	0.050	1.979
	$U[5.0C', 10.0C']$	12.1	0.050	0.828	12.2	0.100	0.820	12.1	0.050	1.344	12.2	0.000	2.034
	$U[10.0C', 20.0C']$	12.4	0.100	0.931	12.5	0.050	0.795	12.4	0.200	1.318	12.3	0.050	2.066
50	$U[0.0C', 0.5C']$	13.0	0.100	2.108	13.0	0.100	2.076	12.7	0.050	2.560	13.0	0.100	2.841
	$U[0.5C', 1.0C']$	12.5	0.050	1.994	12.6	0.100	2.112	12.5	0.050	2.412	12.6	0.100	2.883
	$U[1.0C', 4.0C']$	12.0	0.000	1.869	12.0	0.000	1.872	12.0	0.000	2.291	12.0	0.000	3.119
	$U[0.0C', 5.0C']$	12.0	0.000	1.833	12.0	0.000	1.858	12.0	0.000	2.284	12.0	0.000	3.065
	$U[5.0C', 10.0C']$	12.1	0.050	2.030	12.1	0.050	2.243	12.1	0.050	2.536	12.0	0.000	3.217
	$U[10.0C', 20.0C']$	12.2	0.100	2.106	12.3	0.050	2.166	12.0	0.000	3.000	12.1	0.050	3.505

Table 6.11: Results for a set of 5 instances of size 90 and density 0.8

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	17.1	0.050	0.089	16.9	0.150	0.091	16.8	0.200	0.493	16.9	0.150	1.026
	$U[0.5C', 1.0C']$	16.4	0.100	0.084	16.2	0.100	0.076	16.4	0.000	0.505	16.2	0.000	1.179
	$U[1.0C', 4.0C']$	16.1	0.050	0.081	16.0	0.100	0.078	16.1	0.050	0.523	16.3	0.050	1.141
	$U[0.0C', 5.0C']$	16.3	0.050	0.077	16.1	0.050	0.078	16.3	0.150	0.493	16.0	0.100	1.218
	$U[5.0C', 10.0C']$	16.1	0.050	0.083	16.4	0.000	0.080	16.3	0.050	0.489	16.2	0.000	1.153
	$U[10.0C', 20.0C']$	16.1	0.050	0.085	16.2	0.100	0.085	16.1	0.050	0.536	16.3	0.050	1.179
10	$U[0.0C', 0.5C']$	16.6	0.100	0.895	17.0	0.100	0.766	16.7	0.150	1.072	17.2	0.100	1.597
	$U[0.5C', 1.0C']$	16.1	0.050	0.656	16.3	0.350	0.648	16.2	0.000	1.119	16.2	0.100	1.723
	$U[1.0C', 4.0C']$	15.9	0.050	0.682	15.8	0.000	0.696	15.8	0.000	1.122	15.8	0.000	1.848
	$U[0.0C', 5.0C']$	15.8	0.000	0.679	15.8	0.000	0.652	15.8	0.000	1.083	15.8	0.000	1.867
	$U[5.0C', 10.0C']$	15.9	0.050	0.699	15.8	0.000	0.740	15.8	0.000	1.197	15.8	0.000	1.925
	$U[10.0C', 20.0C']$	16.0	0.100	0.735	16.0	0.000	0.737	16.1	0.050	1.158	15.9	0.050	1.852
20	$U[0.0C', 0.5C']$	16.6	0.200	1.627	16.9	0.150	1.467	16.4	0.000	1.939	17.0	0.100	2.123
	$U[0.5C', 1.0C']$	16.4	0.100	1.283	16.2	0.100	1.412	16.3	0.050	1.643	16.2	0.100	2.317
	$U[1.0C', 4.0C']$	15.8	0.000	1.308	15.9	0.050	1.235	15.8	0.000	1.742	15.8	0.000	2.422
	$U[0.0C', 5.0C']$	15.8	0.000	1.302	15.9	0.050	1.378	15.8	0.000	1.715	15.8	0.000	2.406
	$U[5.0C', 10.0C']$	15.9	0.050	1.372	15.8	0.000	1.448	15.8	0.000	1.815	15.8	0.000	2.455
	$U[10.0C', 20.0C']$	16.0	0.000	1.413	15.8	0.000	1.478	15.8	0.000	1.880	15.9	0.050	2.513
50	$U[0.0C', 0.5C']$	17.0	0.100	3.405	16.9	0.050	3.484	16.9	0.150	3.922	17.1	0.150	4.539
	$U[0.5C', 1.0C']$	16.2	0.100	3.441	16.4	0.100	3.133	16.1	0.050	3.523	16.1	0.050	4.228
	$U[1.0C', 4.0C']$	15.8	0.000	3.019	15.8	0.000	3.062	15.8	0.000	3.485	15.8	0.000	4.214
	$U[0.0C', 5.0C']$	15.8	0.000	3.173	15.8	0.000	3.071	15.8	0.000	3.459	15.8	0.000	4.229
	$U[5.0C', 10.0C']$	15.8	0.000	3.263	15.8	0.000	3.300	15.8	0.000	3.770	15.8	0.000	4.329
	$U[10.0C', 20.0C']$	15.8	0.000	3.451	15.9	0.050	3.436	15.9	0.050	3.800	15.8	0.000	4.562

Table 6.12: Results for a set of 5 instances of size 90 and density 0.9

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	3.0	0.000	0.001	3.0	0.000	0.001	3.0	0.000	0.023	3.0	0.000	0.034
	$U[0.5C', 1.0C']$	3.0	0.000	0.001	3.0	0.000	0.001	3.0	0.000	0.021	3.0	0.000	0.031
	$U[1.0C', 4.0C']$	3.0	0.000	0.001	3.0	0.000	0.001	3.0	0.000	0.021	3.0	0.000	0.032
	$U[0.0C', 5.0C']$	3.0	0.000	0.001	3.0	0.000	0.001	3.0	0.000	0.018	3.0	0.000	0.036
	$U[5.0C', 10.0C']$	3.0	0.000	0.001	3.0	0.000	0.001	3.0	0.000	0.029	3.0	0.000	0.035
	$U[10.0C', 20.0C']$	3.0	0.000	0.001	3.0	0.000	0.001	3.0	0.000	0.021	3.0	0.000	0.036
10	$U[0.0C', 0.5C']$	3.0	0.000	0.001	3.0	0.000	0.001	3.0	0.000	0.026	3.0	0.000	0.031
	$U[0.5C', 1.0C']$	3.0	0.000	0.001	3.0	0.000	0.001	3.0	0.000	0.025	3.0	0.000	0.038
	$U[1.0C', 4.0C']$	3.0	0.000	0.001	3.0	0.000	0.001	3.0	0.000	0.023	3.0	0.000	0.037
	$U[0.0C', 5.0C']$	3.0	0.000	0.001	3.0	0.000	0.001	3.0	0.000	0.027	3.0	0.000	0.035
	$U[5.0C', 10.0C']$	3.0	0.000	0.001	3.0	0.000	0.001	3.0	0.000	0.026	3.0	0.000	0.034
	$U[10.0C', 20.0C']$	3.0	0.000	0.002	3.0	0.000	0.001	3.0	0.000	0.025	3.0	0.000	0.033
20	$U[0.0C', 0.5C']$	3.0	0.000	0.009	3.0	0.000	0.001	3.0	0.000	0.029	3.0	0.000	0.036
	$U[0.5C', 1.0C']$	3.0	0.000	0.003	3.0	0.000	0.001	3.0	0.000	0.023	3.0	0.000	0.037
	$U[1.0C', 4.0C']$	3.0	0.000	0.003	3.0	0.000	0.001	3.0	0.000	0.025	3.0	0.000	0.036
	$U[0.0C', 5.0C']$	3.0	0.000	0.003	3.0	0.000	0.001	3.0	0.000	0.024	3.0	0.000	0.037
	$U[5.0C', 10.0C']$	3.0	0.000	0.003	3.0	0.000	0.001	3.0	0.000	0.022	3.0	0.000	0.034
	$U[10.0C', 20.0C']$	3.0	0.000	0.003	3.0	0.000	0.002	3.0	0.000	0.021	3.0	0.000	0.035
50	$U[0.0C', 0.5C']$	3.0	0.000	0.005	3.0	0.000	0.003	3.0	0.000	0.030	3.0	0.000	0.038
	$U[0.5C', 1.0C']$	3.0	0.000	0.004	3.0	0.000	0.003	3.0	0.000	0.025	3.0	0.000	0.034
	$U[1.0C', 4.0C']$	3.0	0.000	0.003	3.0	0.000	0.003	3.0	0.000	0.023	3.0	0.000	0.035
	$U[0.0C', 5.0C']$	3.0	0.000	0.004	3.0	0.000	0.003	3.0	0.000	0.022	3.0	0.000	0.036
	$U[5.0C', 10.0C']$	3.0	0.000	0.004	3.0	0.000	0.003	3.0	0.000	0.030	3.0	0.000	0.036
	$U[10.0C', 20.0C']$	3.0	0.000	0.004	3.0	0.000	0.004	3.0	0.000	0.024	3.0	0.000	0.036

Table 6.13: Results for a set of 5 instances of size 20 and density 0.5

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	4.0	0.000	0.002	4.0	0.000	0.001	4.0	0.000	0.073	4.1	0.050	0.119
	$U[0.5C', 1.0C']$	4.0	0.000	0.002	4.0	0.000	0.001	4.0	0.000	0.075	4.0	0.000	0.128
	$U[1.0C', 4.0C']$	4.0	0.000	0.001	4.0	0.000	0.001	4.0	0.000	0.076	4.0	0.000	0.127
	$U[0.0C', 5.0C']$	4.0	0.000	0.001	4.0	0.000	0.001	4.0	0.000	0.069	4.0	0.000	0.128
	$U[5.0C', 10.0C']$	4.0	0.000	0.001	4.0	0.000	0.001	4.0	0.000	0.069	4.0	0.000	0.127
	$U[10.0C', 20.0C']$	4.0	0.000	0.001	4.0	0.000	0.001	4.0	0.000	0.070	4.0	0.000	0.136
10	$U[0.0C', 0.5C']$	4.0	0.000	0.007	4.0	0.000	0.006	4.0	0.000	0.078	4.1	0.050	0.130
	$U[0.5C', 1.0C']$	4.0	0.000	0.006	4.0	0.000	0.007	4.0	0.000	0.076	4.0	0.000	0.136
	$U[1.0C', 4.0C']$	4.0	0.000	0.006	4.0	0.000	0.006	4.0	0.000	0.078	4.0	0.000	0.137
	$U[0.0C', 5.0C']$	4.0	0.000	0.006	4.0	0.000	0.006	4.0	0.000	0.077	4.0	0.000	0.139
	$U[5.0C', 10.0C']$	4.0	0.000	0.006	4.0	0.000	0.006	4.0	0.000	0.082	4.0	0.000	0.131
	$U[10.0C', 20.0C']$	4.0	0.000	0.007	4.0	0.000	0.007	4.0	0.000	0.076	4.0	0.000	0.133
20	$U[0.0C', 0.5C']$	4.0	0.000	0.011	4.0	0.000	0.012	4.0	0.000	0.078	4.0	0.000	0.139
	$U[0.5C', 1.0C']$	4.0	0.000	0.012	4.0	0.000	0.012	4.0	0.000	0.089	4.0	0.000	0.144
	$U[1.0C', 4.0C']$	4.0	0.000	0.012	4.0	0.000	0.013	4.0	0.000	0.082	4.0	0.000	0.138
	$U[0.0C', 5.0C']$	4.0	0.000	0.011	4.0	0.000	0.011	4.0	0.000	0.079	4.0	0.000	0.137
	$U[5.0C', 10.0C']$	4.0	0.000	0.012	4.0	0.000	0.012	4.0	0.000	0.081	4.0	0.000	0.137
	$U[10.0C', 20.0C']$	4.0	0.000	0.013	4.0	0.000	0.012	4.0	0.000	0.081	4.0	0.000	0.144
50	$U[0.0C', 0.5C']$	4.0	0.000	0.029	4.0	0.000	0.027	4.0	0.000	0.091	4.1	0.050	0.148
	$U[0.5C', 1.0C']$	4.0	0.000	0.028	4.0	0.000	0.027	4.0	0.000	0.098	4.0	0.000	0.154
	$U[1.0C', 4.0C']$	4.0	0.000	0.026	4.0	0.000	0.026	4.0	0.000	0.088	4.0	0.000	0.156
	$U[0.0C', 5.0C']$	4.0	0.000	0.026	4.0	0.000	0.026	4.0	0.000	0.100	4.0	0.000	0.156
	$U[5.0C', 10.0C']$	4.0	0.000	0.029	4.0	0.000	0.028	4.0	0.000	0.093	4.0	0.000	0.154
	$U[10.0C', 20.0C']$	4.0	0.000	0.030	4.0	0.000	0.030	4.0	0.000	0.101	4.0	0.000	0.153

Table 6.14: Results for a set of 5 instances of size 40 and density 0.5

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	5.6	0.100	0.005	5.3	0.050	0.004	5.2	0.100	0.128	5.5	0.050	0.261
	$U[0.5C', 1.0C']$	5.6	0.100	0.006	5.4	0.100	0.004	5.4	0.000	0.117	5.4	0.100	0.266
	$U[1.0C', 4.0C']$	5.7	0.050	0.004	5.3	0.150	0.004	5.2	0.100	0.122	5.4	0.100	0.265
	$U[0.0C', 5.0C']$	5.3	0.150	0.004	5.3	0.050	0.004	5.2	0.100	0.125	5.6	0.100	0.248
	$U[5.0C', 10.0C']$	5.7	0.050	0.004	5.3	0.150	0.004	5.4	0.100	0.114	5.3	0.050	0.277
	$U[10.0C', 20.0C']$	5.9	0.050	0.004	5.8	0.100	0.004	5.4	0.100	0.110	5.8	0.000	0.220
10	$U[0.0C', 0.5C']$	5.4	0.100	0.024	5.1	0.050	0.026	5.3	0.050	0.139	5.2	0.100	0.298
	$U[0.5C', 1.0C']$	5.1	0.050	0.026	5.2	0.100	0.024	5.1	0.050	0.142	5.1	0.050	0.323
	$U[1.0C', 4.0C']$	5.0	0.000	0.024	5.0	0.000	0.024	5.0	0.000	0.148	5.0	0.000	0.306
	$U[0.0C', 5.0C']$	5.0	0.000	0.023	5.0	0.000	0.023	5.0	0.000	0.144	5.0	0.000	0.323
	$U[5.0C', 10.0C']$	5.0	0.000	0.023	5.0	0.000	0.024	5.0	0.000	0.151	5.0	0.000	0.323
	$U[10.0C', 20.0C']$	5.0	0.000	0.028	5.2	0.100	0.027	5.0	0.000	0.157	5.2	0.100	0.309
20	$U[0.0C', 0.5C']$	5.2	0.000	0.045	5.3	0.050	0.047	5.2	0.000	0.157	5.3	0.050	0.319
	$U[0.5C', 1.0C']$	5.1	0.050	0.052	5.3	0.150	0.042	5.2	0.100	0.156	5.3	0.050	0.324
	$U[1.0C', 4.0C']$	5.0	0.000	0.043	5.0	0.000	0.042	5.0	0.000	0.164	5.0	0.000	0.341
	$U[0.0C', 5.0C']$	5.0	0.000	0.044	5.0	0.000	0.043	5.0	0.000	0.167	5.0	0.000	0.339
	$U[5.0C', 10.0C']$	5.0	0.000	0.045	5.0	0.000	0.043	5.0	0.000	0.171	5.0	0.000	0.338
	$U[10.0C', 20.0C']$	5.0	0.000	0.046	5.0	0.000	0.051	5.0	0.000	0.168	5.0	0.000	0.358
50	$U[0.0C', 0.5C']$	5.0	0.000	0.117	5.0	0.000	0.118	5.2	0.100	0.214	5.1	0.050	0.392
	$U[0.5C', 1.0C']$	5.2	0.100	0.115	5.1	0.050	0.118	5.1	0.050	0.228	5.3	0.050	0.374
	$U[1.0C', 4.0C']$	5.0	0.000	0.096	5.0	0.000	0.097	5.0	0.000	0.218	5.0	0.000	0.401
	$U[0.0C', 5.0C']$	5.0	0.000	0.099	5.0	0.000	0.101	5.0	0.000	0.216	5.0	0.000	0.394
	$U[5.0C', 10.0C']$	5.0	0.000	0.103	5.0	0.000	0.103	5.0	0.000	0.230	5.0	0.000	0.409
	$U[10.0C', 20.0C']$	5.0	0.000	0.119	5.0	0.000	0.114	5.0	0.000	0.229	5.0	0.000	0.403

Table 6.15: Results for a set of 5 instances of size 60 and density 0.5

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	6.0	0.000	0.006	6.0	0.000	0.006	6.0	0.000	0.132	6.0	0.000	0.362
	$U[0.5C', 1.0C']$	6.0	0.000	0.006	6.0	0.000	0.006	6.1	0.050	0.127	6.1	0.050	0.338
	$U[1.0C', 4.0C']$	6.0	0.000	0.006	6.0	0.000	0.006	6.0	0.000	0.134	6.1	0.050	0.347
	$U[0.0C', 5.0C']$	6.0	0.000	0.007	6.1	0.050	0.006	6.0	0.000	0.130	6.0	0.000	0.348
	$U[5.0C', 10.0C']$	6.0	0.000	0.006	6.0	0.000	0.006	6.0	0.000	0.132	6.1	0.050	0.332
	$U[10.0C', 20.0C']$	6.2	0.000	0.006	6.0	0.000	0.006	6.1	0.050	0.120	6.0	0.000	0.356
10	$U[0.0C', 0.5C']$	6.0	0.000	0.032	6.0	0.000	0.032	6.0	0.000	0.160	6.0	0.000	0.372
	$U[0.5C', 1.0C']$	6.0	0.000	0.033	6.0	0.000	0.032	6.0	0.000	0.154	6.0	0.000	0.379
	$U[1.0C', 4.0C']$	6.0	0.000	0.032	6.0	0.000	0.033	6.0	0.000	0.150	6.0	0.000	0.379
	$U[0.0C', 5.0C']$	6.0	0.000	0.032	6.0	0.000	0.031	6.0	0.000	0.155	6.0	0.000	0.381
	$U[5.0C', 10.0C']$	6.0	0.000	0.033	6.0	0.000	0.032	6.0	0.000	0.155	6.0	0.000	0.378
	$U[10.0C', 20.0C']$	6.0	0.000	0.034	6.0	0.000	0.034	6.0	0.000	0.153	6.0	0.000	0.370
20	$U[0.0C', 0.5C']$	6.0	0.000	0.061	6.0	0.000	0.061	6.0	0.000	0.179	6.0	0.000	0.401
	$U[0.5C', 1.0C']$	6.0	0.000	0.059	6.0	0.000	0.058	6.0	0.000	0.179	6.0	0.000	0.400
	$U[1.0C', 4.0C']$	6.0	0.000	0.062	6.0	0.000	0.060	6.0	0.000	0.185	6.0	0.000	0.417
	$U[0.0C', 5.0C']$	6.0	0.000	0.060	6.0	0.000	0.060	6.0	0.000	0.187	6.0	0.000	0.417
	$U[5.0C', 10.0C']$	6.0	0.000	0.063	6.0	0.000	0.062	6.0	0.000	0.191	6.0	0.000	0.396
	$U[10.0C', 20.0C']$	6.0	0.000	0.065	6.0	0.000	0.065	6.0	0.000	0.196	6.0	0.000	0.412
50	$U[0.0C', 0.5C']$	6.0	0.000	0.144	6.0	0.000	0.141	6.0	0.000	0.261	6.0	0.000	0.463
	$U[0.5C', 1.0C']$	6.0	0.000	0.139	6.0	0.000	0.136	6.0	0.000	0.267	6.0	0.000	0.493
	$U[1.0C', 4.0C']$	6.0	0.000	0.142	6.0	0.000	0.141	6.0	0.000	0.271	6.0	0.000	0.487
	$U[0.0C', 5.0C']$	6.0	0.000	0.147	6.0	0.000	0.144	6.0	0.000	0.273	6.0	0.000	0.476
	$U[5.0C', 10.0C']$	6.0	0.000	0.153	6.0	0.000	0.152	6.0	0.000	0.281	6.0	0.000	0.495
	$U[10.0C', 20.0C']$	6.0	0.000	0.157	6.0	0.000	0.156	6.0	0.000	0.282	6.0	0.000	0.492

Table 6.16: Results for a set of 5 instances of size 70 and density 0.5

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	6.7	0.050	0.009	6.7	0.050	0.009	7.0	0.000	0.148	6.8	0.100	0.423
	$U[0.5C', 1.0C']$	7.0	0.000	0.008	6.9	0.050	0.009	7.0	0.000	0.145	6.8	0.000	0.442
	$U[1.0C', 4.0C']$	6.8	0.000	0.008	6.9	0.050	0.008	7.0	0.000	0.147	6.8	0.100	0.436
	$U[0.0C', 5.0C']$	6.8	0.000	0.010	7.0	0.000	0.009	7.0	0.000	0.143	6.9	0.050	0.414
	$U[5.0C', 10.0C']$	6.9	0.050	0.008	6.7	0.050	0.009	6.9	0.050	0.157	6.8	0.000	0.443
	$U[10.0C', 20.0C']$	7.0	0.000	0.008	7.0	0.000	0.009	6.9	0.050	0.147	7.0	0.000	0.410
10	$U[0.0C', 0.5C']$	6.7	0.050	0.053	6.8	0.100	0.051	6.5	0.050	0.217	6.6	0.100	0.515
	$U[0.5C', 1.0C']$	6.5	0.050	0.061	6.8	0.100	0.050	6.8	0.100	0.200	6.6	0.000	0.515
	$U[1.0C', 4.0C']$	6.5	0.050	0.053	6.4	0.000	0.059	6.4	0.100	0.217	6.4	0.000	0.536
	$U[0.0C', 5.0C']$	6.5	0.050	0.053	6.4	0.000	0.058	6.5	0.050	0.202	6.3	0.050	0.550
	$U[5.0C', 10.0C']$	6.4	0.000	0.063	6.6	0.100	0.055	6.4	0.100	0.218	6.4	0.000	0.536
	$U[10.0C', 20.0C']$	6.8	0.100	0.061	6.6	0.000	0.061	7.0	0.000	0.187	6.7	0.150	0.500
20	$U[0.0C', 0.5C']$	6.8	0.100	0.090	6.7	0.050	0.096	6.6	0.100	0.255	6.7	0.150	0.564
	$U[0.5C', 1.0C']$	6.7	0.050	0.100	6.7	0.150	0.096	6.9	0.050	0.230	7.0	0.000	0.498
	$U[1.0C', 4.0C']$	6.2	0.100	0.109	6.6	0.000	0.105	6.3	0.050	0.271	6.4	0.000	0.597
	$U[0.0C', 5.0C']$	6.1	0.050	0.116	6.3	0.050	0.111	6.3	0.050	0.264	6.3	0.050	0.620
	$U[5.0C', 10.0C']$	6.5	0.050	0.109	6.4	0.000	0.113	6.4	0.000	0.272	6.3	0.050	0.634
	$U[10.0C', 20.0C']$	6.8	0.100	0.114	6.7	0.050	0.130	6.8	0.000	0.249	6.7	0.050	0.580
50	$U[0.0C', 0.5C']$	6.7	0.150	0.240	6.9	0.050	0.219	6.6	0.000	0.404	6.6	0.000	0.677
	$U[0.5C', 1.0C']$	6.6	0.000	0.260	6.6	0.100	0.251	6.7	0.150	0.389	6.6	0.000	0.711
	$U[1.0C', 4.0C']$	6.3	0.050	0.255	6.1	0.050	0.284	6.1	0.050	0.448	6.2	0.000	0.768
	$U[0.0C', 5.0C']$	6.2	0.000	0.263	6.2	0.000	0.270	6.1	0.050	0.475	6.2	0.000	0.750
	$U[5.0C', 10.0C']$	6.3	0.050	0.270	6.3	0.050	0.279	6.4	0.000	0.414	6.2	0.000	0.795
	$U[10.0C', 20.0C']$	6.4	0.000	0.303	6.3	0.150	0.329	6.6	0.100	0.426	6.3	0.050	0.844

Table 6.17: Results for a set of 5 instances of size 80 and density 0.5

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	8.2	0.027	0.021	8.2	0.038	0.023	8.2	0.055	0.225	8.3	0.044	0.613
	$U[0.5C', 1.0C']$	8.1	0.016	0.020	8.1	0.033	0.021	8.1	0.050	0.226	8.1	0.050	0.666
	$U[1.0C', 4.0C']$	8.0	0.038	0.021	8.1	0.016	0.021	8.1	0.027	0.227	8.0	0.016	0.667
	$U[0.0C', 5.0C']$	8.0	0.038	0.022	8.1	0.005	0.021	8.1	0.027	0.229	8.0	0.033	0.672
	$U[5.0C', 10.0C']$	8.1	0.033	0.021	8.1	0.038	0.022	8.1	0.016	0.222	8.1	0.022	0.641
	$U[10.0C', 20.0C']$	8.2	0.016	0.021	8.2	0.016	0.021	8.2	0.016	0.226	8.1	0.027	0.628
10	$U[0.0C', 0.5C']$	8.1	0.038	0.165	8.2	0.055	0.150	8.2	0.033	0.347	8.2	0.027	0.776
	$U[0.5C', 1.0C']$	7.9	0.022	0.160	8.0	0.038	0.155	8.0	0.050	0.359	8.0	0.033	0.787
	$U[1.0C', 4.0C']$	7.8	0.011	0.155	7.8	0.016	0.159	7.8	0.011	0.389	7.9	0.016	0.819
	$U[0.0C', 5.0C']$	7.9	0.016	0.158	7.9	0.011	0.156	7.8	0.000	0.380	7.8	0.011	0.835
	$U[5.0C', 10.0C']$	7.9	0.022	0.159	7.9	0.022	0.165	7.9	0.022	0.376	7.9	0.016	0.832
	$U[10.0C', 20.0C']$	8.0	0.033	0.170	8.0	0.038	0.169	7.9	0.027	0.390	8.0	0.027	0.814
20	$U[0.0C', 0.5C']$	8.1	0.050	0.332	8.2	0.044	0.319	8.2	0.077	0.525	8.2	0.038	0.892
	$U[0.5C', 1.0C']$	8.0	0.055	0.309	8.1	0.038	0.292	8.0	0.027	0.505	8.0	0.033	0.930
	$U[1.0C', 4.0C']$	7.8	0.000	0.298	7.8	0.005	0.315	7.8	0.011	0.518	7.8	0.005	0.968
	$U[0.0C', 5.0C']$	7.8	0.005	0.293	7.8	0.005	0.305	7.8	0.011	0.517	7.8	0.000	0.982
	$U[5.0C', 10.0C']$	7.8	0.005	0.320	7.8	0.005	0.332	7.8	0.000	0.530	7.9	0.016	0.994
	$U[10.0C', 20.0C']$	7.9	0.011	0.322	7.9	0.027	0.348	8.0	0.022	0.528	7.9	0.005	0.987
50	$U[0.0C', 0.5C']$	8.1	0.044	0.834	8.2	0.050	0.767	8.2	0.072	0.932	8.2	0.050	1.324
	$U[0.5C', 1.0C']$	8.0	0.044	0.723	8.0	0.027	0.715	7.9	0.016	0.913	8.0	0.044	1.321
	$U[1.0C', 4.0C']$	7.8	0.000	0.710	7.8	0.000	0.710	7.8	0.000	0.915	7.8	0.000	1.366
	$U[0.0C', 5.0C']$	7.8	0.011	0.716	7.8	0.011	0.721	7.8	0.000	0.929	7.8	0.005	1.378
	$U[5.0C', 10.0C']$	7.8	0.000	0.764	7.8	0.005	0.784	7.8	0.011	0.963	7.8	0.011	1.432
	$U[10.0C', 20.0C']$	7.9	0.022	0.814	7.9	0.011	0.844	7.9	0.016	1.028	7.8	0.011	1.481

Table 6.18: Results for a set of 5 instances of size 90 and density 0.5

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	7.6	0.100	0.018	7.8	0.000	0.017	7.6	0.100	0.240	7.8	0.100	0.735
	$U[0.5C', 1.0C']$	7.8	0.000	0.017	7.8	0.000	0.016	7.7	0.050	0.234	7.6	0.100	0.801
	$U[1.0C', 4.0C']$	7.7	0.050	0.017	7.8	0.000	0.016	7.8	0.000	0.226	7.7	0.050	0.767
	$U[0.0C', 5.0C']$	7.8	0.000	0.016	7.8	0.000	0.016	7.8	0.000	0.218	7.7	0.050	0.774
	$U[5.0C', 10.0C']$	7.9	0.050	0.016	7.8	0.000	0.017	7.7	0.050	0.223	7.8	0.000	0.716
	$U[10.0C', 20.0C']$	8.0	0.000	0.016	8.0	0.000	0.016	7.9	0.050	0.219	8.0	0.000	0.711
10	$U[0.0C', 0.5C']$	7.8	0.100	0.104	7.6	0.100	0.111	7.6	0.100	0.325	7.7	0.050	0.834
	$U[0.5C', 1.0C']$	7.6	0.000	0.102	7.6	0.100	0.103	7.7	0.050	0.321	7.7	0.050	0.859
	$U[1.0C', 4.0C']$	7.2	0.000	0.120	7.1	0.050	0.122	7.1	0.050	0.375	7.2	0.100	1.019
	$U[0.0C', 5.0C']$	7.1	0.050	0.124	7.0	0.000	0.118	7.1	0.050	0.373	7.1	0.050	1.022
	$U[5.0C', 10.0C']$	7.4	0.100	0.138	7.3	0.050	0.136	7.4	0.200	0.357	7.4	0.200	0.929
	$U[10.0C', 20.0C']$	7.8	0.000	0.110	7.8	0.000	0.114	7.8	0.000	0.321	7.8	0.000	0.840
20	$U[0.0C', 0.5C']$	7.6	0.100	0.210	7.8	0.000	0.196	7.3	0.050	0.466	7.6	0.100	0.963
	$U[0.5C', 1.0C']$	7.5	0.050	0.229	7.6	0.100	0.201	7.5	0.150	0.430	7.3	0.150	1.045
	$U[1.0C', 4.0C']$	7.0	0.000	0.233	7.0	0.000	0.232	7.0	0.000	0.483	7.0	0.000	1.139
	$U[0.0C', 5.0C']$	7.0	0.000	0.232	7.0	0.000	0.227	7.2	0.100	0.460	7.0	0.000	1.110
	$U[5.0C', 10.0C']$	7.3	0.050	0.259	7.1	0.050	0.261	7.3	0.050	0.471	7.3	0.050	1.061
	$U[10.0C', 20.0C']$	7.8	0.000	0.212	7.8	0.000	0.216	7.5	0.150	0.471	7.5	0.150	1.003
50	$U[0.0C', 0.5C']$	7.8	0.100	0.478	7.7	0.050	0.502	7.5	0.150	0.729	7.6	0.100	1.272
	$U[0.5C', 1.0C']$	7.2	0.100	0.658	7.4	0.100	0.582	7.6	0.100	0.695	7.6	0.100	1.239
	$U[1.0C', 4.0C']$	7.0	0.000	0.544	7.0	0.000	0.523	7.0	0.000	0.764	7.0	0.000	1.427
	$U[0.0C', 5.0C']$	7.0	0.000	0.521	7.0	0.000	0.538	7.0	0.000	0.758	7.0	0.000	1.422
	$U[5.0C', 10.0C']$	7.0	0.000	0.622	7.1	0.050	0.582	7.0	0.000	0.827	7.1	0.050	1.455
	$U[10.0C', 20.0C']$	7.7	0.050	0.539	7.5	0.050	0.579	7.7	0.050	0.735	7.6	0.100	1.303

Table 6.19: Results for a set of 5 instances of size 100 and density 0.5

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	8.7	0.050	0.032	9.0	0.000	0.029	8.9	0.050	0.349	8.9	0.050	1.201
	$U[0.5C', 1.0C']$	8.8	0.100	0.030	9.0	0.000	0.028	8.9	0.050	0.337	8.9	0.050	1.213
	$U[1.0C', 4.0C']$	8.7	0.050	0.032	8.9	0.050	0.029	9.0	0.000	0.341	8.9	0.050	1.173
	$U[0.0C', 5.0C']$	9.0	0.000	0.028	8.7	0.050	0.031	8.8	0.100	0.348	8.8	0.000	1.211
	$U[5.0C', 10.0C']$	9.0	0.000	0.029	8.9	0.050	0.029	9.0	0.000	0.337	9.0	0.000	1.139
	$U[10.0C', 20.0C']$	9.0	0.000	0.031	9.0	0.000	0.030	9.0	0.000	0.349	9.0	0.000	1.144
10	$U[0.0C', 0.5C']$	8.9	0.050	0.202	8.6	0.000	0.242	8.8	0.000	0.513	8.8	0.100	1.412
	$U[0.5C', 1.0C']$	8.7	0.050	0.237	8.9	0.050	0.192	8.7	0.050	0.532	8.7	0.050	1.390
	$U[1.0C', 4.0C']$	8.5	0.050	0.216	8.6	0.000	0.205	8.6	0.000	0.528	8.6	0.000	1.473
	$U[0.0C', 5.0C']$	8.6	0.000	0.211	8.6	0.000	0.208	8.6	0.000	0.525	8.5	0.050	1.498
	$U[5.0C', 10.0C']$	8.6	0.000	0.218	8.6	0.000	0.213	8.6	0.000	0.554	8.7	0.050	1.433
	$U[10.0C', 20.0C']$	8.9	0.050	0.221	8.8	0.100	0.231	8.9	0.050	0.535	8.8	0.000	1.388
20	$U[0.0C', 0.5C']$	8.7	0.050	0.436	8.8	0.100	0.388	8.8	0.000	0.718	8.6	0.000	1.677
	$U[0.5C', 1.0C']$	8.8	0.100	0.376	8.7	0.050	0.413	8.6	0.000	0.760	8.9	0.050	1.494
	$U[1.0C', 4.0C']$	8.6	0.000	0.408	8.6	0.000	0.390	8.5	0.050	0.744	8.5	0.050	1.694
	$U[0.0C', 5.0C']$	8.6	0.000	0.411	8.6	0.000	0.394	8.5	0.050	0.740	8.5	0.050	1.679
	$U[5.0C', 10.0C']$	8.6	0.000	0.438	8.6	0.000	0.434	8.6	0.000	0.750	8.6	0.000	1.667
	$U[10.0C', 20.0C']$	8.9	0.050	0.421	8.8	0.000	0.434	8.6	0.000	0.787	8.8	0.000	1.666
50	$U[0.0C', 0.5C']$	8.8	0.100	0.944	8.6	0.000	0.977	8.6	0.000	1.342	8.7	0.050	2.152
	$U[0.5C', 1.0C']$	8.7	0.050	1.009	8.7	0.050	0.947	8.7	0.050	1.374	8.6	0.000	2.193
	$U[1.0C', 4.0C']$	8.6	0.000	0.949	8.6	0.000	0.943	8.5	0.050	1.312	8.6	0.000	2.212
	$U[0.0C', 5.0C']$	8.4	0.100	1.113	8.6	0.000	0.965	8.5	0.050	1.354	8.5	0.050	2.249
	$U[5.0C', 10.0C']$	8.6	0.000	0.998	8.5	0.050	1.047	8.6	0.000	1.300	8.6	0.000	2.232
	$U[10.0C', 20.0C']$	8.6	0.000	1.060	8.6	0.000	1.117	8.7	0.050	1.363	8.6	0.000	2.318

Table 6.20: Results for a set of 5 instances of size 120 and density 0.5

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.25C', 0.75C']$	53.00	0.000	32.675	52.40	0.240	45.955	52.00	0.000	41.061	52.80	0.160	131.369
	$U[0.0C', 1.0C']$	53.00	0.000	31.822	53.00	0.000	31.307	52.60	0.240	38.698	53.00	0.000	124.405
	$U[0.0C', 0.5C']$	52.00	0.000	49.998	52.60	0.240	40.508	52.00	0.000	47.886	52.80	0.160	133.227
	$U[0.5C', 1.0C']$	52.60	0.240	34.443	52.40	0.240	34.702	53.00	0.000	34.162	52.00	0.000	151.490
	$U[0.25C', 1.0C']$	53.00	0.000	33.513	52.40	0.240	34.969	53.00	0.000	35.207	53.00	0.000	126.708
	$U[0.0C', 0.75C']$	52.40	0.240	37.164	52.40	0.240	42.677	52.40	0.240	43.436	52.40	0.20	137.571
5	$U[0.25C', 0.75C']$	52.00	0.000	175.018	51.60	0.240	222.313	52.00	0.000	167.028	52.00	0.000	263.785
	$U[0.0C', 1.0C']$	51.40	0.240	192.997	52.00	0.000	166.878	52.00	0.000	168.842	52.00	0.000	270.638
	$U[0.0C', 0.5C']$	51.40	0.240	188.598	51.40	0.240	194.900	51.40	0.240	234.086	52.00	0.000	267.352
	$U[0.5C', 1.0C']$	52.00	0.000	167.531	51.40	0.240	197.548	51.40	0.250	191.290	51.40	0.250	301.400
	$U[0.25C', 1.0C']$	51.40	0.240	227.016	51.40	0.240	190.509	51.40	0.240	226.595	52.00	0.000	273.516
	$U[0.0C', 0.75C']$	52.00	0.000	166.399	51.00	0.000	243.717	51.80	0.160	188.605	51.80	0.160	323.258
10	$U[0.25C', 0.75C']$	51.00	0.000	460.830	51.00	0.000	499.770	51.80	0.160	385.627	51.00	0.000	580.569
	$U[0.0C', 1.0C']$	51.00	0.000	445.430	51.00	0.000	441.279	51.00	0.000	556.089	51.00	0.000	1920.230
	$U[0.0C', 0.5C']$	51.00	0.000	438.898	51.00	0.000	506.921	51.00	0.000	491.451	51.00	0.000	574.642
	$U[0.5C', 1.0C']$	51.00	0.000	434.163	51.40	0.240	368.134	51.00	0.000	467.440	51.00	0.000	617.425
	$U[0.25C', 1.0C']$	51.80	0.160	365.680	51.00	0.000	424.486	51.60	0.240	365.924	51.40	0.240	441.895
	$U[0.0C', 0.75C']$	51.00	0.000	425.001	51.00	0.000	526.258	51.40	0.240	353.324	51.40	0.240	479.716

Table 6.21: Results for the instance *dsjc500.5-1*, 500 nodes, density 0.5

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.25C', 0.75C']$	47.60	0.240	72.492	47.00	0.000	69.580	47.00	0.000	121.744	48.00	0.000	702.030
	$U[0.0C', 1.0C']$	47.00	0.000	77.980	47.00	0.000	78.475	47.00	0.000	126.041	48.00	0.000	722.381
	$U[0.0C', 0.5C']$	47.00	0.000	77.742	47.60	0.240	71.457	47.00	0.000	118.374	48.00	0.000	647.080
	$U[0.5C', 0.1C']$	47.20	0.160	80.400	47.00	0.000	72.520	47.40	0.240	102.338	47.00	0.000	761.492
	$U[0.25C', 1.0C']$	47.20	0.160	66.099	47.00	0.000	85.592	47.00	0.000	118.374	47.40	0.240	752.992
	$U[0.0C', 0.75C']$	47.60	0.240	74.900	47.20	0.160	65.508	47.00	0.000	118.374	47.60	0.240	669.113
5	$U[0.25C', 0.75C']$	47.00	0.000	329.858	47.00	0.000	322.690	47.00	0.000	341.401	47.00	0.000	911.078
	$U[0.0C', 1.0C']$	47.00	0.000	314.639	47.00	0.000	312.814	47.00	0.000	329.006	47.00	0.000	909.702
	$U[0.0C', 0.5C']$	47.00	0.000	336.046	47.00	0.000	368.138	47.00	0.000	363.048	47.00	0.000	893.171
	$U[0.5C', 0.1C']$	47.00	0.000	329.366	46.60	0.240	355.754	47.00	0.000	369.581	47.00	0.000	939.086
	$U[0.25C', 1.0C']$	47.00	0.000	320.355	46.60	0.240	504.976	47.00	0.000	312.525	47.00	0.000	888.474
	$U[0.0C', 0.75C']$	47.00	0.000	319.387	47.00	0.000	321.539	47.00	0.000	381.417	47.00	0.000	899.100
10	$U[0.25C', 0.75C']$	47.00	0.000	650.358	47.00	0.000	600.810	47.00	0.000	782.341	47.00	0.000	1340.031
	$U[0.0C', 1.0C']$	46.40	0.240	657.860	46.40	0.240	771.054	47.00	0.000	842.114	47.00	0.000	1112.001
	$U[0.0C', 0.5C']$	47.00	0.000	651.221	46.60	0.240	712.167	47.00	0.000	666.702	47.00	0.000	1260.525
	$U[0.5C', 0.1C']$	47.00	0.000	610.881	46.40	0.240	655.999	46.00	0.000	1090.255	47.00	0.000	1332.405
	$U[0.25C', 1.0C']$	46.40	0.240	811.390	47.00	0.000	618.188	47.00	0.000	699.847	47.00	0.000	1201.992
	$U[0.0C', 0.75C']$	47.00	0.000	630.789	46.60	0.240	700.052	47.00	0.000	947.012	47.00	0.000	1417.935

Table 6.22: Results for the instance *dsjc500.5-2*, 1000 nodes, density 0.5

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.25C', 0.75C']$	45.00	0.000	115.018	45.00	0.000	115.547	45.00	0.000	205.556	45.00	0.000	3110.445
	$U[0.0C', 1.0C']$	45.00	0.000	124.909	45.00	0.000	119.600	45.00	0.000	245.091	45.00	0.000	3101.009
	$U[0.0C', 0.5C']$	45.00	0.000	117.858	45.00	0.000	130.135	45.00	0.000	199.366	45.00	0.000	2960.582
	$U[0.5C', 1.0C']$	45.00	0.000	115.410	45.00	0.000	113.664	45.00	0.00	210.217	44.60	0.240	3227.712
	$U[0.25C', 1.0C']$	45.00	0.000	113.382	45.00	0.000	119.870	45.00	0.000	182.176	45.00	0.000	3298.511
	$U[0.0C', 0.75C']$	45.00	0.000	113.593	45.00	0.000	114.424	45.40	0.240	224.569	45.00	0.000	3205.006
5	$U[0.25C', 0.75C']$	44.00	0.000	775.920	44.20	0.160	644.067	44.00	0.000	712.253	44.00	0.000	3801.001
	$U[0.0C', 1.0C']$	44.00	0.000	692.584	44.40	0.240	590.315	44.00	0.000	736.866	44.00	0.000	3989.886
	$U[0.0C', 0.5C']$	44.00	0.000	887.549	44.60	0.240	569.560	44.00	0.000	770.456	44.00	0.000	4252.012
	$U[0.5C', 1.0C']$	44.40	0.240	535.744	44.00	0.000	981.468	44.80	0.160	631.256	44.60	0.240	3525.024
	$U[0.25C', 1.0C']$	44.80	0.160	623.681	44.60	0.240	547.132	44.00	0.000	705.102	44.00	0.000	3612.583
	$U[0.0C', 0.75C']$	44.60	0.240	716.675	44.40	0.240	564.862	44.00	0.000	681.207	44.00	0.000	4328.666
10	$U[0.25C', 0.75C']$	44.00	0.000	1711.281	44.00	0.000	1284.477	44.00	0.000	991.903	44.00	0.000	4385.033
	$U[0.0C', 1.0C']$	44.00	0.000	1609.692	44.20	0.160	1398.949	44.00	0.000	1013.891	44.00	0.000	4441.113
	$U[0.0C', 0.5C']$	44.00	0.000	1504.814	44.00	0.000	1624.962	44.00	0.000	1271.812	44.00	0.000	4641.228
	$U[0.5C', 1.0C']$	44.60	0.240	1156.730	44.00	0.000	1739.053	44.40	0.240	1163.476	44.00	0.000	4935.751
	$U[0.25C', 1.0C']$	44.00	0.000	1282.196	44.00	0.000	1772.908	44.60	0.240	1351.233	44.00	0.000	5011.565
	$U[0.0C', 0.75C']$	44.00	0.000	1928.361	44.00	0.000	1792.404	44.40	0.240	1291.088	44.00	0.000	4505.852

Table 6.23: Results for the instance *dsjc500.5-3*, 1500 nodes, density 0.5

Parameters		Random			OneStepCD			ILP1			ILP2		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.25C', 0.75C']$	43.40	0.240	200.361	43.00	0.000	178.387	43.00	0.000	311.715	43.20	0.160	7530.236
	$U[0.0C', 1.0C']$	43.20	0.160	185.824	43.00	0.000	179.494	43.00	0.000	341.112	43.80	0.160	7012.431
	$U[0.0C', 0.5C']$	44.00	0.000	143.937	43.60	0.240	186.869	43.00	0.000	333.319	43.80	0.160	7171.777
	$U[0.5C', 1.0C']$	43.00	0.000	214.545	43.60	0.240	142.063	43.00	0.000	338.309	43.60	0.240	7439.572
	$U[0.25C', 1.0C']$	43.60	0.240	145.004	43.00	0.000	251.143	43.00	0.000	302.122	44.00	0.000	7621.502
	$U[0.0C', 0.75C']$	43.60	0.240	218.761	43.20	0.160	187.378	43.00	0.000	335.834	43.40	0.240	7478.121
5	$U[0.25C', 0.75C']$	43.00	0.000	780.378	43.00	0.000	963.153	43.00	0.000	978.203	43.00	0.000	8956.555
	$U[0.0C', 1.0C']$	42.40	0.240	849.693	42.80	0.160	771.423	43.00	0.000	1122.429	42.80	0.160	8701.683
	$U[0.0C', 0.5C']$	43.00	0.000	808.077	43.00	0.000	848.376	43.00	0.000	1006.318	43.00	0.000	8622.681
	$U[0.5C', 1.0C']$	43.00	0.000	781.823	43.00	0.000	823.835	43.00	0.000	958.897	43.00	0.000	9115.008
	$U[0.25C', 1.0C']$	43.00	0.000	776.229	43.00	0.000	806.833	43.00	0.000	989.006	43.00	0.000	9012.904
	$U[0.0C', 0.75C']$	43.00	0.000	823.599	43.00	0.000	809.126	43.00	0.000	1007.065	43.00	0.000	8848.775
10	$U[0.25C', 0.75C']$	43.00	0.000	1619.182	43.00	0.000	1711.629	43.00	0.000	1674.249	43.00	0.000	9246.012
	$U[0.0C', 1.0C']$	43.00	0.000	1570.523	43.00	0.000	1628.829	42.80	0.160	1569.004	43.00	0.000	9006.112
	$U[0.0C', 0.5C']$	43.00	0.000	1532.691	42.40	0.240	2145.856	43.00	0.000	1762.306	43.00	0.000	9176.079
	$U[0.5C', 1.0C']$	42.80	0.180	1554.850	43.00	0.000	1558.656	42.80	0.160	1710.961	43.00	0.000	9047.702
	$U[0.25C', 1.0C']$	43.00	0.000	1567.553	42.60	0.240	1799.667	43.00	0.000	1821.938	43.00	0.000	9312.528
	$U[0.0C', 0.75C']$	43.00	0.000	1529.261	43.00	0.000	1554.409	43.00	0.000	1701.039	43.00	0.000	9199.499

Table 6.24: Results for the instance *dsjc500.5-4*, 2000 nodes, density 0.5

Variants

As discussed in section 5.4, variants for both ILPs have been created by removing the inequation that restricts conflicts inside the recolored set of clusters. In tables 6.25 to 6.30 the standard ILPs marked as *ILP1* and *ILP2* are compared to their variants *ILP1** and *ILP2** by evaluating three instances of different size as well as three instances of different density. It can be seen that removing the aforementioned constraint does not increase the solution quality.

Furthermore experiments have been performed, placing the recently recolored set of clusters on the tabu list. In tables 6.31 to 6.36 sets diversing in size and density have been evaluated using $F_{max} = 5$. The parameter *TTRecolored* sets the number of iterations as $TabuSize = TTRecolored * C'$ for all the node-color pairs of the recolored set of clusters to remain on the tabu list.

Parameters		ILP1			ILP1*			ILP2			ILP2*		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	10.3	0.150	0.312	10.6	0.100	0.135	10.5	0.150	0.823	10.4	0.100	0.602
	$U[0.5C', 1.0C']$	10.4	0.000	0.302	10.4	0.100	0.131	10.2	0.100	0.875	10.3	0.050	0.617
	$U[1.0C', 4.0C']$	10.0	0.000	0.326	10.1	0.050	0.151	10.2	0.100	0.868	10.2	0.000	0.628
	$U[0.0C', 5.0C']$	10.0	0.000	0.337	10.1	0.050	0.138	10.2	0.100	0.917	10.3	0.050	0.632
	$U[5.0C', 10.0C']$	10.3	0.150	0.308	10.2	0.000	0.142	10.4	0.100	0.820	10.3	0.050	0.610
	$U[10.0C', 20.0C']$	10.5	0.150	0.295	10.9	0.050	0.112	10.6	0.100	0.793	10.7	0.050	0.545
10	$U[0.0C', 0.5C']$	10.2	0.100	0.542	10.7	0.050	0.295	10.7	0.150	0.952	10.3	0.050	0.799
	$U[0.5C', 1.0C']$	10.2	0.100	0.508	10.1	0.050	0.356	10.2	0.100	1.096	10.2	0.000	0.800
	$U[1.0C', 4.0C']$	10.0	0.000	0.493	10.0	0.000	0.314	10.0	0.000	1.098	10.0	0.000	0.827
	$U[0.0C', 5.0C']$	10.0	0.000	0.493	10.0	0.000	0.319	10.0	0.000	1.081	10.0	0.000	0.823
	$U[5.0C', 10.0C']$	10.0	0.000	0.500	10.0	0.000	0.322	10.0	0.000	1.109	10.0	0.000	0.828
	$U[10.0C', 20.0C']$	10.0	0.000	0.531	10.1	0.050	0.362	10.0	0.000	1.114	10.0	0.000	0.871
20	$U[0.0C', 0.5C']$	10.4	0.100	0.738	10.7	0.150	0.491	10.3	0.150	1.327	10.4	0.200	0.991
	$U[0.5C', 1.0C']$	10.1	0.050	0.745	10.1	0.050	0.587	10.1	0.050	1.345	10.1	0.050	1.023
	$U[1.0C', 4.0C']$	10.0	0.000	0.673	10.0	0.000	0.499	10.0	0.000	1.281	10.0	0.000	0.993
	$U[0.0C', 5.0C']$	10.0	0.000	0.682	10.0	0.000	0.494	10.0	0.000	1.290	10.0	0.000	1.001
	$U[5.0C', 10.0C']$	10.0	0.000	0.690	10.0	0.000	0.517	10.0	0.000	1.289	10.0	0.000	1.013
	$U[10.0C', 20.0C']$	10.0	0.000	0.721	10.0	0.000	0.548	10.0	0.000	1.320	10.0	0.000	1.048
50	$U[0.0C', 0.5C']$	10.3	0.150	1.386	10.6	0.100	1.105	10.7	0.150	1.694	10.2	0.000	1.709
	$U[0.5C', 1.0C']$	10.3	0.050	1.346	10.0	0.000	1.199	10.0	0.000	1.948	10.2	0.100	1.526
	$U[1.0C', 4.0C']$	10.0	0.000	1.207	10.0	0.000	1.060	10.0	0.000	1.778	10.0	0.000	1.523
	$U[0.0C', 5.0C']$	10.0	0.000	1.211	10.0	0.000	1.058	10.0	0.000	1.812	10.0	0.000	1.533
	$U[5.0C', 10.0C']$	10.0	0.000	1.231	10.0	0.000	1.093	10.0	0.000	1.837	10.0	0.000	1.553
	$U[10.0C', 20.0C']$	10.0	0.000	1.295	10.0	0.000	1.176	10.0	0.000	1.910	10.0	0.000	1.677

Table 6.25: ILP variants compared on a set of 5 instances with 90 nodes and a density of 0.7 each.

Parameters		ILP1			ILP1*			ILP2			ILP2*		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	13.1	0.150	0.394	12.8	0.000	0.215	12.9	0.050	1.045	12.8	0.000	0.851
	$U[0.5C', 1.0C']$	12.7	0.050	0.439	12.8	0.100	0.204	12.7	0.050	1.088	12.7	0.050	0.848
	$U[1.0C', 4.0C']$	12.7	0.050	0.426	12.8	0.000	0.213	12.6	0.000	1.081	12.7	0.050	0.870
	$U[0.0C', 5.0C']$	12.7	0.050	0.446	12.7	0.050	0.221	12.8	0.000	1.048	12.5	0.050	0.882
	$U[5.0C', 10.0C']$	12.7	0.050	0.426	12.8	0.000	0.203	12.7	0.050	1.094	12.8	0.000	0.832
	$U[10.0C', 20.0C']$	12.8	0.000	0.426	12.8	0.000	0.195	12.8	0.100	1.069	12.8	0.000	0.850
10	$U[0.0C', 0.5C']$	12.8	0.000	0.720	12.7	0.050	0.546	12.9	0.050	1.294	13.0	0.000	1.049
	$U[0.5C', 1.0C']$	12.7	0.050	0.691	12.5	0.150	0.556	12.5	0.050	1.417	12.4	0.000	1.208
	$U[1.0C', 4.0C']$	12.2	0.100	0.746	12.1	0.050	0.543	12.2	0.100	1.508	12.0	0.000	1.321
	$U[0.0C', 5.0C']$	12.2	0.100	0.765	12.1	0.050	0.521	12.2	0.100	1.522	12.2	0.000	1.218
	$U[5.0C', 10.0C']$	12.4	0.000	0.745	12.1	0.050	0.580	12.3	0.050	1.525	12.2	0.000	1.284
	$U[10.0C', 20.0C']$	12.4	0.000	0.779	12.4	0.100	0.529	12.5	0.050	1.439	12.5	0.150	1.208
20	$U[0.0C', 0.5C']$	13.0	0.000	0.930	13.1	0.150	0.787	12.8	0.200	1.671	12.7	0.050	1.435
	$U[0.5C', 1.0C']$	12.5	0.050	1.068	12.7	0.050	0.779	12.8	0.000	1.571	12.6	0.000	1.398
	$U[1.0C', 4.0C']$	12.1	0.050	1.101	12.0	0.000	0.949	12.2	0.000	1.778	12.0	0.000	1.620
	$U[0.0C', 5.0C']$	12.0	0.000	1.178	12.0	0.000	0.848	12.1	0.050	1.876	12.0	0.000	1.634
	$U[5.0C', 10.0C']$	12.2	0.000	1.088	12.2	0.100	0.858	12.2	0.000	1.813	12.1	0.050	1.657
	$U[10.0C', 20.0C']$	12.2	0.100	1.170	12.5	0.050	0.899	12.6	0.100	1.771	12.2	0.000	1.692
50	$U[0.0C', 0.5C']$	12.9	0.050	1.930	13.1	0.050	1.870	13.0	0.100	2.468	12.8	0.100	2.313
	$U[0.5C', 1.0C']$	12.8	0.000	1.716	12.6	0.100	1.776	12.7	0.050	2.487	12.7	0.050	2.294
	$U[1.0C', 4.0C']$	12.0	0.000	2.094	12.0	0.000	1.753	12.0	0.000	2.765	12.0	0.000	2.463
	$U[0.0C', 5.0C']$	12.0	0.000	2.054	12.0	0.000	1.824	12.0	0.000	2.791	12.0	0.000	2.687
	$U[5.0C', 10.0C']$	12.0	0.000	2.201	12.1	0.050	1.844	12.1	0.050	2.837	12.0	0.000	2.696
	$U[10.0C', 20.0C']$	12.3	0.150	2.140	12.2	0.100	2.080	12.3	0.050	2.962	12.2	0.100	2.676

Table 6.26: ILP variants compared on a set of 5 instances with 90 nodes and a density of 0.8 each.

Parameters		ILP1			ILP1*			ILP2			ILP2*		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	16.7	0.250	0.450	17.0	0.100	0.235	16.9	0.250	1.001	16.8	0.300	0.877
	$U[0.5C', 1.0C']$	16.4	0.100	0.477	16.3	0.050	0.279	16.2	0.000	1.139	16.6	0.100	0.909
	$U[1.0C', 4.0C']$	16.1	0.050	0.513	16.3	0.050	0.266	16.2	0.000	1.125	16.3	0.050	0.996
	$U[0.0C', 5.0C']$	16.0	0.000	0.534	16.1	0.050	0.300	16.2	0.000	1.112	16.2	0.000	0.990
	$U[5.0C', 10.0C']$	16.1	0.050	0.510	16.3	0.050	0.252	16.2	0.000	1.096	16.2	0.000	0.998
	$U[10.0C', 20.0C']$	16.4	0.000	0.473	16.1	0.050	0.294	16.2	0.000	1.101	16.2	0.000	0.994
10	$U[0.0C', 0.5C']$	16.6	0.300	0.994	16.8	0.300	0.830	16.8	0.300	1.561	16.7	0.050	1.484
	$U[0.5C', 1.0C']$	16.1	0.050	0.938	16.2	0.300	0.790	16.3	0.050	1.584	16.2	0.000	1.474
	$U[1.0C', 4.0C']$	15.8	0.000	1.019	15.8	0.000	0.758	15.8	0.000	1.731	15.8	0.000	1.571
	$U[0.0C', 5.0C']$	15.8	0.000	1.005	15.9	0.050	0.763	15.8	0.000	1.694	16.0	0.100	1.517
	$U[5.0C', 10.0C']$	15.8	0.000	1.103	15.9	0.050	0.809	15.8	0.000	1.754	15.8	0.000	1.603
	$U[10.0C', 20.0C']$	16.1	0.050	1.003	15.8	0.000	0.949	16.0	0.000	1.701	16.0	0.000	1.563
20	$U[0.0C', 0.5C']$	17.0	0.200	1.491	17.1	0.250	1.384	17.1	0.150	2.114	16.7	0.050	1.980
	$U[0.5C', 1.0C']$	16.2	0.000	1.430	16.2	0.100	1.361	16.0	0.000	2.203	16.3	0.150	1.877
	$U[1.0C', 4.0C']$	15.8	0.000	1.499	15.8	0.000	1.289	15.8	0.000	2.181	15.8	0.000	2.039
	$U[0.0C', 5.0C']$	15.8	0.000	1.532	15.8	0.000	1.328	15.8	0.000	2.177	15.8	0.000	2.127
	$U[5.0C', 10.0C']$	15.9	0.050	1.546	15.8	0.000	1.370	15.8	0.000	2.227	15.8	0.000	2.178
	$U[10.0C', 20.0C']$	16.0	0.000	1.585	16.0	0.000	1.337	15.8	0.000	2.273	16.0	0.000	2.105
50	$U[0.0C', 0.5C']$	16.7	0.350	3.210	16.8	0.100	3.289	17.2	0.200	3.570	17.2	0.000	3.566
	$U[0.5C', 1.0C']$	16.2	0.000	2.842	16.1	0.050	2.740	16.3	0.250	3.523	16.0	0.000	3.637
	$U[1.0C', 4.0C']$	15.8	0.000	2.937	15.8	0.000	2.775	15.8	0.000	3.617	15.8	0.000	3.526
	$U[0.0C', 5.0C']$	15.8	0.000	2.948	15.8	0.000	2.766	15.8	0.000	3.688	15.8	0.000	3.526
	$U[5.0C', 10.0C']$	15.8	0.000	3.241	15.8	0.000	2.838	15.8	0.000	3.762	15.8	0.000	3.697
	$U[10.0C', 20.0C']$	15.8	0.000	3.457	15.8	0.000	3.065	15.8	0.000	3.903	15.8	0.000	3.831

Table 6.27: ILP variants compared on a set of 5 instances with 90 nodes and a density of 0.9 each.

Parameters		ILP1			ILP1*			ILP2			ILP2*		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	8.2	0.055	0.216	8.2	0.050	0.100	8.3	0.044	0.604	8.1	0.050	0.459
	$U[0.5C', 1.0C']$	8.1	0.011	0.226	8.1	0.038	0.099	8.0	0.033	0.662	8.1	0.033	0.464
	$U[1.0C', 4.0C']$	8.0	0.027	0.223	8.1	0.016	0.102	8.1	0.033	0.652	8.0	0.022	0.473
	$U[0.0C', 5.0C']$	8.1	0.027	0.225	8.0	0.022	0.101	8.0	0.022	0.662	8.0	0.033	0.480
	$U[5.0C', 10.0C']$	8.1	0.033	0.221	8.1	0.050	0.102	8.1	0.027	0.646	8.1	0.033	0.467
	$U[10.0C', 20.0C']$	8.2	0.033	0.219	8.1	0.038	0.100	8.2	0.038	0.633	8.2	0.033	0.453
10	$U[0.0C', 0.5C']$	8.2	0.033	0.354	8.2	0.061	0.238	8.1	0.072	0.780	8.1	0.061	0.592
	$U[0.5C', 1.0C']$	8.0	0.022	0.350	8.0	0.050	0.241	8.0	0.033	0.786	8.0	0.033	0.608
	$U[1.0C', 4.0C']$	7.8	0.011	0.376	7.8	0.000	0.250	7.9	0.016	0.835	7.9	0.016	0.632
	$U[0.0C', 5.0C']$	7.9	0.022	0.378	7.9	0.005	0.240	7.9	0.016	0.820	7.9	0.011	0.631
	$U[5.0C', 10.0C']$	7.9	0.016	0.378	7.9	0.005	0.252	7.9	0.022	0.830	7.9	0.011	0.632
	$U[10.0C', 20.0C']$	8.0	0.027	0.376	8.0	0.016	0.255	7.9	0.027	0.825	8.0	0.033	0.627
20	$U[0.0C', 0.5C']$	8.1	0.050	0.508	8.2	0.050	0.412	8.2	0.066	0.933	8.2	0.027	0.711
	$U[0.5C', 1.0C']$	8.0	0.022	0.506	8.0	0.038	0.370	8.0	0.038	0.936	8.0	0.038	0.734
	$U[1.0C', 4.0C']$	7.8	0.005	0.520	7.8	0.000	0.392	7.8	0.000	0.971	7.8	0.005	0.782
	$U[0.0C', 5.0C']$	7.8	0.005	0.517	7.8	0.000	0.395	7.8	0.000	0.973	7.8	0.011	0.786
	$U[5.0C', 10.0C']$	7.9	0.005	0.533	7.9	0.011	0.408	7.9	0.011	0.976	7.9	0.000	0.778
	$U[10.0C', 20.0C']$	7.9	0.016	0.534	7.9	0.033	0.430	7.9	0.016	0.985	7.9	0.016	0.778
50	$U[0.0C', 0.5C']$	8.1	0.038	0.973	8.2	0.094	0.825	8.2	0.033	1.393	8.1	0.072	1.208
	$U[0.5C', 1.0C']$	8.0	0.033	0.890	8.0	0.022	0.802	8.0	0.027	1.351	8.0	0.027	1.181
	$U[1.0C', 4.0C']$	7.8	0.011	0.922	7.8	0.005	0.798	7.8	0.005	1.384	7.8	0.005	1.185
	$U[0.0C', 5.0C']$	7.8	0.005	0.919	7.8	0.000	0.805	7.8	0.000	1.386	7.8	0.005	1.181
	$U[5.0C', 10.0C']$	7.8	0.005	0.958	7.8	0.000	0.848	7.8	0.000	1.440	7.8	0.005	1.242
	$U[10.0C', 20.0C']$	7.9	0.016	1.022	7.8	0.011	0.903	7.9	0.005	1.482	7.9	0.016	1.291

Table 6.28: ILP variants compared on a set of 5 instances with 90 nodes and a density of 0.5 each.

Parameters		ILP1			ILP1*			ILP2			ILP2*		
ItMax	TabuTenure	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)	obj	sd	time(s)
1	$U[0.0C', 0.5C']$	7.8	0.000	0.221	8.0	0.000	0.085	7.8	0.000	0.756	7.8	0.000	0.527
	$U[0.5C', 1.0C']$	7.7	0.050	0.216	7.8	0.100	0.105	7.8	0.000	0.744	7.8	0.000	0.531
	$U[1.0C', 4.0C']$	7.8	0.000	0.232	7.9	0.050	0.088	7.8	0.000	0.744	7.8	0.000	0.529
	$U[0.0C', 5.0C']$	7.8	0.100	0.223	7.8	0.000	0.087	7.8	0.100	0.735	7.7	0.050	0.577
	$U[5.0C', 10.0C']$	7.7	0.050	0.237	7.7	0.050	0.096	7.9	0.050	0.699	7.9	0.050	0.527
	$U[10.0C', 20.0C']$	8.0	0.000	0.216	7.9	0.050	0.087	7.8	0.100	0.733	7.9	0.050	0.490
10	$U[0.0C', 0.5C']$	7.6	0.100	0.321	7.6	0.100	0.194	7.6	0.100	0.877	7.8	0.000	0.615
	$U[0.5C', 1.0C']$	7.6	0.000	0.324	7.5	0.150	0.181	7.7	0.150	0.858	7.5	0.150	0.700
	$U[1.0C', 4.0C']$	7.1	0.050	0.359	7.0	0.000	0.214	7.0	0.000	1.034	7.1	0.050	0.789
	$U[0.0C', 5.0C']$	7.2	0.100	0.376	7.0	0.000	0.206	7.0	0.000	1.050	7.2	0.100	0.747
	$U[5.0C', 10.0C']$	7.5	0.050	0.349	7.6	0.100	0.195	7.4	0.200	0.940	7.4	0.000	0.700
	$U[10.0C', 20.0C']$	7.8	0.000	0.320	7.8	0.000	0.181	7.8	0.000	0.831	7.7	0.050	0.631
20	$U[0.0C', 0.5C']$	7.6	0.200	0.443	7.6	0.100	0.270	7.7	0.050	0.952	7.6	0.100	0.780
	$U[0.5C', 1.0C']$	7.6	0.100	0.414	7.5	0.150	0.299	7.8	0.000	0.923	7.7	0.050	0.727
	$U[1.0C', 4.0C']$	7.0	0.000	0.483	7.0	0.000	0.331	7.1	0.050	1.128	7.0	0.000	0.861
	$U[0.0C', 5.0C']$	7.0	0.000	0.492	7.0	0.000	0.342	7.0	0.000	1.138	7.0	0.000	0.885
	$U[5.0C', 10.0C']$	7.5	0.150	0.438	7.1	0.050	0.326	7.3	0.050	1.071	7.1	0.050	0.870
	$U[10.0C', 20.0C']$	7.7	0.050	0.429	7.7	0.050	0.311	7.7	0.050	0.949	7.7	0.050	0.760
50	$U[0.0C', 0.5C']$	7.6	0.000	0.716	7.5	0.150	0.572	7.5	0.250	1.300	7.6	0.100	1.027
	$U[0.5C', 1.0C']$	7.4	0.100	0.758	7.5	0.050	0.642	7.6	0.100	1.269	7.6	0.100	1.043
	$U[1.0C', 4.0C']$	7.0	0.000	0.803	7.0	0.000	0.627	7.0	0.000	1.402	7.0	0.000	1.206
	$U[0.0C', 5.0C']$	7.0	0.000	0.774	7.0	0.000	0.672	7.0	0.000	1.418	7.0	0.000	1.188
	$U[5.0C', 10.0C']$	7.1	0.050	0.829	7.1	0.050	0.723	7.0	0.000	1.500	7.1	0.050	1.246
	$U[10.0C', 20.0C']$	7.3	0.150	0.816	7.3	0.150	0.756	7.5	0.050	1.399	7.5	0.050	1.169

Table 6.29: ILP variants compared on a set of 5 instances with 100 nodes and a density of 0.5 each.

Parameters		ILP1			ILP1*			ILP2			ILP2*		
ItMax	TabuTenure	<i>obj</i>	<i>sd</i>	<i>time</i> (s)	<i>obj</i>	<i>sd</i>	<i>time</i> (s)	<i>obj</i>	<i>sd</i>	<i>time</i> (s)	<i>obj</i>	<i>sd</i>	<i>time</i> (s)
1	$U[0.0C', 0.5C']$	8.8	0.100	0.355	8.9	0.050	0.126	8.9	0.050	1.222	8.7	0.050	0.938
	$U[0.5C', 1.0C']$	8.8	0.000	0.360	8.8	0.000	0.150	8.9	0.050	1.192	8.8	0.100	0.923
	$U[1.0C', 4.0C']$	8.7	0.050	0.366	8.9	0.050	0.132	8.9	0.050	1.149	8.9	0.050	0.875
	$U[0.0C', 5.0C']$	8.8	0.000	0.356	8.9	0.050	0.126	9.0	0.000	1.183	8.8	0.100	0.934
	$U[5.0C', 10.0C']$	9.0	0.000	0.335	8.9	0.050	0.133	8.6	0.000	1.330	8.9	0.050	0.892
	$U[10.0C', 20.0C']$	9.0	0.000	0.326	9.0	0.000	0.121	9.0	0.000	1.172	9.0	0.000	0.831
10	$U[0.0C', 0.5C']$	8.7	0.050	0.511	8.7	0.050	0.317	8.8	0.100	1.396	8.8	0.000	1.065
	$U[0.5C', 1.0C']$	8.6	0.000	0.565	8.7	0.050	0.326	8.6	0.000	1.497	8.7	0.050	1.140
	$U[1.0C', 4.0C']$	8.6	0.000	0.541	8.6	0.000	0.326	8.6	0.000	1.447	8.6	0.000	1.129
	$U[0.0C', 5.0C']$	8.6	0.000	0.541	8.6	0.000	0.319	8.5	0.050	1.486	8.6	0.000	1.136
	$U[5.0C', 10.0C']$	8.6	0.000	0.566	8.6	0.000	0.341	8.6	0.000	1.451	8.8	0.100	1.089
	$U[10.0C', 20.0C']$	8.9	0.050	0.538	8.8	0.000	0.355	8.9	0.050	1.361	8.9	0.050	1.111
20	$U[0.0C', 0.5C']$	8.7	0.050	0.716	9.0	0.000	0.468	8.6	0.000	1.696	8.6	0.000	1.340
	$U[0.5C', 1.0C']$	8.6	0.000	0.726	8.6	0.000	0.576	8.5	0.050	1.670	8.6	0.000	1.325
	$U[1.0C', 4.0C']$	8.6	0.000	0.714	8.5	0.050	0.532	8.5	0.050	1.697	8.6	0.000	1.367
	$U[0.0C', 5.0C']$	8.6	0.000	0.728	8.6	0.000	0.513	8.5	0.050	1.699	8.6	0.000	1.356
	$U[5.0C', 10.0C']$	8.6	0.000	0.726	8.6	0.000	0.543	8.6	0.000	1.659	8.6	0.000	1.395
	$U[10.0C', 20.0C']$	8.6	0.000	0.787	8.9	0.050	0.533	8.8	0.000	1.675	8.9	0.050	1.262
50	$U[0.0C', 0.5C']$	9.0	0.000	1.156	8.7	0.050	1.065	8.7	0.050	2.217	8.8	0.100	1.829
	$U[0.5C', 1.0C']$	8.8	0.000	1.213	8.7	0.050	1.081	8.8	0.000	2.165	8.6	0.000	1.958
	$U[1.0C', 4.0C']$	8.3	0.050	1.405	8.5	0.050	1.111	8.5	0.050	2.289	8.6	0.000	1.872
	$U[0.0C', 5.0C']$	8.6	0.000	1.282	8.5	0.050	1.154	8.6	0.000	2.169	8.6	0.000	1.928
	$U[5.0C', 10.0C']$	8.6	0.000	1.322	8.6	0.000	1.109	8.6	0.000	2.190	8.6	0.000	1.952
	$U[10.0C', 20.0C']$	8.6	0.000	1.480	8.7	0.050	1.179	8.6	0.000	2.350	8.7	0.050	1.947

Table 6.30: ILP variants compared on a set of 5 instances with 120 nodes and a density of 0.5 each.

Parameters		OneStepCD			ILP1			ILP2		
RecoloredTT	TabuTenure	<i>obj</i>	<i>sd</i>	<i>time</i>	<i>obj</i>	<i>sd</i>	<i>time</i>	<i>obj</i>	<i>sd</i>	<i>time</i>
0.0	$U[0.0C', 0.5C']$	10.3	0.050	0.222	10.4	0.000	0.479	10.3	0.150	1.081
	$U[0.5C', 1.0C']$	10.1	0.050	0.141	10.1	0.050	0.432	10.0	0.000	1.102
	$U[1.0C', 4.0C']$	10.0	0.000	0.113	10.0	0.000	0.410	10.0	0.000	1.042
	$U[0.0C', 5.0C']$	10.0	0.000	0.114	10.0	0.000	0.414	10.0	0.000	1.056
	$U[5.0C', 10.0C']$	10.0	0.000	0.122	10.0	0.000	0.435	10.0	0.000	1.072
	$U[10.0C', 20.0C']$	10.2	0.100	0.142	10.1	0.050	0.425	10.2	0.100	1.020
0.3	$U[0.0C', 0.5C']$	10.4	0.000	0.126	10.7	0.150	0.359	10.5	0.150	0.940
	$U[0.5C', 1.0C']$	10.0	0.000	0.122	10.2	0.000	0.410	10.2	0.100	1.032
	$U[1.0C', 4.0C']$	10.0	0.000	0.110	10.0	0.000	0.434	10.0	0.000	1.032
	$U[0.0C', 5.0C']$	10.0	0.000	0.121	10.0	0.000	0.411	10.0	0.000	1.046
	$U[5.0C', 10.0C']$	10.1	0.050	0.124	10.0	0.000	0.440	10.0	0.000	1.053
	$U[10.0C', 20.0C']$	10.2	0.100	0.133	10.0	0.000	0.446	10.0	0.000	1.070
0.5	$U[0.0C', 0.5C']$	10.6	0.100	0.112	10.4	0.200	0.383	10.2	0.100	1.024
	$U[0.5C', 1.0C']$	10.2	0.000	0.119	10.0	0.000	0.419	10.3	0.050	0.983
	$U[1.0C', 4.0C']$	10.0	0.000	0.114	10.0	0.000	0.404	10.0	0.000	1.020
	$U[0.0C', 5.0C']$	10.0	0.000	0.131	10.0	0.000	0.414	10.0	0.000	1.057
	$U[5.0C', 10.0C']$	10.0	0.000	0.118	10.0	0.000	0.430	10.0	0.000	1.058
	$U[10.0C', 20.0C']$	10.2	0.100	0.134	10.1	0.050	0.416	10.2	0.000	1.009
1.0	$U[0.0C', 0.5C']$	10.4	0.000	0.117	10.7	0.050	0.348	10.5	0.150	0.972
	$U[0.5C', 1.0C']$	10.2	0.000	0.114	10.1	0.050	0.418	10.0	0.000	1.081
	$U[1.0C', 4.0C']$	10.0	0.000	0.113	10.0	0.000	0.413	10.0	0.000	1.050
	$U[0.0C', 5.0C']$	10.0	0.000	0.112	10.0	0.000	0.400	10.0	0.000	1.058
	$U[5.0C', 10.0C']$	10.0	0.000	0.122	10.0	0.000	0.415	10.0	0.000	1.077
	$U[10.0C', 20.0C']$	10.0	0.000	0.161	10.1	0.050	0.421	10.1	0.050	1.117
2.0	$U[0.0C', 0.5C']$	10.6	0.000	0.117	10.6	0.100	0.367	10.1	0.050	1.088
	$U[0.5C', 1.0C']$	10.1	0.050	0.132	10.1	0.050	0.407	10.3	0.050	0.997
	$U[1.0C', 4.0C']$	10.0	0.000	0.109	10.0	0.000	0.414	10.0	0.000	1.061
	$U[0.0C', 5.0C']$	10.0	0.000	0.116	10.0	0.000	0.415	10.0	0.000	1.132
	$U[5.0C', 10.0C']$	10.0	0.000	0.123	10.0	0.000	0.425	10.0	0.000	1.095
	$U[10.0C', 20.0C']$	10.0	0.000	0.140	10.2	0.100	0.394	10.2	0.100	1.013
5.0	$U[0.0C', 0.5C']$	10.5	0.050	0.120	10.4	0.100	0.397	10.5	0.150	0.934
	$U[0.5C', 1.0C']$	10.0	0.000	0.112	10.1	0.050	0.414	10.2	0.100	1.031
	$U[1.0C', 4.0C']$	10.0	0.000	0.110	10.0	0.000	0.411	10.0	0.000	1.043
	$U[0.0C', 5.0C']$	10.1	0.050	0.111	10.0	0.000	0.421	10.0	0.000	1.040
	$U[5.0C', 10.0C']$	10.0	0.000	0.127	10.0	0.000	0.420	10.0	0.000	1.044
	$U[10.0C', 20.0C']$	10.0	0.000	0.137	10.1	0.050	0.431	10.0	0.000	1.088
10.0	$U[0.0C', 0.5C']$	10.2	0.000	0.146	10.5	0.150	0.395	10.6	0.100	0.905
	$U[0.5C', 1.0C']$	10.1	0.050	0.128	10.1	0.050	0.439	10.2	0.100	1.027
	$U[1.0C', 4.0C']$	10.0	0.000	0.114	10.0	0.000	0.416	10.0	0.000	1.060
	$U[0.0C', 5.0C']$	10.0	0.000	0.111	10.0	0.000	0.415	10.0	0.000	1.045
	$U[5.0C', 10.0C']$	10.1	0.050	0.118	10.0	0.000	0.426	10.0	0.000	1.057
	$U[10.0C', 20.0C']$	10.0	0.000	0.145	10.2	0.100	0.414	10.1	0.050	1.053

Table 6.31: ILP variants compared on a set of 5 instances with 90 nodes and a density of 0.7 each.

Parameters		OneStepCD			ILP1			ILP2		
RecoloredTT	TabuTenure	<i>obj</i>	<i>sd</i>	<i>time</i>	<i>obj</i>	<i>sd</i>	<i>time</i>	<i>obj</i>	<i>sd</i>	<i>time</i>
0.0	$U[0.0C', 0.5C']$	12.8	0.000	0.220	12.9	0.150	0.576	12.9	0.050	1.212
	$U[0.5C', 1.0C']$	12.3	0.050	0.207	12.4	0.100	0.646	12.6	0.000	1.328
	$U[1.0C', 4.0C']$	12.3	0.050	0.195	12.2	0.100	0.623	12.4	0.000	1.362
	$U[0.0C', 5.0C']$	12.1	0.050	0.224	12.3	0.050	0.616	12.3	0.050	1.386
	$U[5.0C', 10.0C']$	12.5	0.050	0.199	12.5	0.050	0.601	12.4	0.100	1.413
	$U[10.0C', 20.0C']$	12.8	0.000	0.182	12.6	0.100	0.610	12.7	0.050	1.284
0.3	$U[0.0C', 0.5C']$	12.8	0.000	0.201	12.8	0.000	0.563	13.0	0.100	1.201
	$U[0.5C', 1.0C']$	12.7	0.050	0.184	12.6	0.000	0.588	12.6	0.100	1.319
	$U[1.0C', 4.0C']$	12.3	0.050	0.192	12.4	0.000	0.597	12.2	0.000	1.413
	$U[0.0C', 5.0C']$	12.2	0.100	0.195	12.2	0.100	0.641	12.2	0.000	1.415
	$U[5.0C', 10.0C']$	12.3	0.050	0.201	12.6	0.100	0.601	12.2	0.000	1.417
	$U[10.0C', 20.0C']$	12.6	0.100	0.194	12.4	0.100	0.651	12.5	0.050	1.332
0.5	$U[0.0C', 0.5C']$	13.0	0.100	0.189	13.0	0.100	0.559	12.9	0.050	1.225
	$U[0.5C', 1.0C']$	12.5	0.150	0.200	12.5	0.050	0.609	12.5	0.050	1.329
	$U[1.0C', 4.0C']$	12.2	0.000	0.195	12.2	0.000	0.639	12.3	0.050	1.437
	$U[0.0C', 5.0C']$	12.3	0.050	0.202	12.2	0.100	0.632	12.3	0.050	1.396
	$U[5.0C', 10.0C']$	12.6	0.100	0.195	12.4	0.100	0.649	12.4	0.100	1.372
	$U[10.0C', 20.0C']$	12.8	0.000	0.181	12.7	0.050	0.602	12.7	0.050	1.273
1.0	$U[0.0C', 0.5C']$	13.0	0.100	0.187	12.9	0.050	0.557	12.8	0.000	1.247
	$U[0.5C', 1.0C']$	12.8	0.000	0.164	12.6	0.000	0.604	12.5	0.050	1.375
	$U[1.0C', 4.0C']$	12.3	0.050	0.185	12.2	0.100	0.628	12.4	0.000	1.368
	$U[0.0C', 5.0C']$	12.2	0.000	0.196	12.2	0.000	0.646	12.4	0.000	1.353
	$U[5.0C', 10.0C']$	12.5	0.050	0.210	12.4	0.100	0.628	12.6	0.100	1.299
	$U[10.0C', 20.0C']$	12.7	0.050	0.186	12.7	0.050	0.594	12.6	0.100	1.307
2.0	$U[0.0C', 0.5C']$	12.7	0.150	0.194	12.8	0.000	0.585	13.0	0.300	1.220
	$U[0.5C', 1.0C']$	12.8	0.000	0.159	12.5	0.050	0.602	12.6	0.000	1.306
	$U[1.0C', 4.0C']$	12.3	0.050	0.179	12.2	0.100	0.662	12.4	0.000	1.364
	$U[0.0C', 5.0C']$	12.1	0.050	0.198	12.2	0.100	0.645	12.4	0.000	1.375
	$U[5.0C', 10.0C']$	12.4	0.100	0.200	12.3	0.150	0.654	12.5	0.050	1.343
	$U[10.0C', 20.0C']$	12.6	0.100	0.187	12.6	0.100	0.597	12.7	0.050	1.267
5.0	$U[0.0C', 0.5C']$	13.0	0.000	0.171	12.8	0.100	0.582	12.7	0.050	1.278
	$U[0.5C', 1.0C']$	12.4	0.000	0.187	12.8	0.000	0.564	12.6	0.100	1.288
	$U[1.0C', 4.0C']$	12.1	0.050	0.210	12.4	0.100	0.617	12.4	0.000	1.351
	$U[0.0C', 5.0C']$	12.3	0.050	0.196	12.3	0.050	0.637	12.4	0.000	1.359
	$U[5.0C', 10.0C']$	12.4	0.000	0.194	12.2	0.000	0.665	12.2	0.000	1.446
	$U[10.0C', 20.0C']$	12.7	0.050	0.195	12.7	0.050	0.614	12.7	0.050	1.262
10.0	$U[0.0C', 0.5C']$	12.8	0.100	0.189	13.1	0.050	0.522	12.9	0.050	1.231
	$U[0.5C', 1.0C']$	12.4	0.100	0.188	12.6	0.100	0.567	12.7	0.050	1.243
	$U[1.0C', 4.0C']$	12.1	0.050	0.195	12.2	0.000	0.610	12.1	0.050	1.445
	$U[0.0C', 5.0C']$	12.3	0.050	0.204	12.3	0.050	0.574	12.3	0.050	1.403
	$U[5.0C', 10.0C']$	12.4	0.100	0.196	12.5	0.050	0.591	12.3	0.050	1.410
	$U[10.0C', 20.0C']$	12.7	0.050	0.182	12.7	0.050	0.575	12.6	0.100	1.355

Table 6.32: ILP variants compared on a set of 5 instances with 90 nodes and a density of 0.8 each.

Parameters		OneStepCD			ILP1			ILP2		
RecoloredTT	TabuTenure	<i>obj</i>	<i>sd</i>	<i>time</i>	<i>obj</i>	<i>sd</i>	<i>time</i>	<i>obj</i>	<i>sd</i>	<i>time</i>
0.0	$U[0.0C', 0.5C']$	16.9	0.250	0.371	16.7	0.050	0.721	17.2	0.300	1.234
	$U[0.5C', 1.0C']$	16.3	0.050	0.309	16.1	0.050	0.731	16.3	0.050	1.365
	$U[1.0C', 4.0C']$	16.0	0.000	0.297	15.8	0.000	0.774	15.9	0.050	1.518
	$U[0.0C', 5.0C']$	16.0	0.100	0.294	15.9	0.050	0.737	16.0	0.100	1.482
	$U[5.0C', 10.0C']$	16.0	0.000	0.306	16.1	0.050	0.743	15.9	0.050	1.515
	$U[10.0C', 20.0C']$	16.0	0.100	0.336	16.0	0.000	0.781	16.1	0.050	1.424
0.3	$U[0.0C', 0.5C']$	16.6	0.100	0.365	16.8	0.100	0.700	17.2	0.100	1.226
	$U[0.5C', 1.0C']$	16.5	0.050	0.296	16.3	0.050	0.683	16.2	0.000	1.387
	$U[1.0C', 4.0C']$	15.8	0.000	0.299	15.9	0.050	0.773	15.9	0.050	1.515
	$U[0.0C', 5.0C']$	15.8	0.000	0.337	15.9	0.050	0.757	16.0	0.100	1.463
	$U[5.0C', 10.0C']$	16.0	0.100	0.337	15.9	0.050	0.814	16.0	0.000	1.449
	$U[10.0C', 20.0C']$	16.1	0.050	0.330	16.1	0.050	0.836	16.0	0.100	1.477
0.5	$U[0.0C', 0.5C']$	16.9	0.250	0.345	16.5	0.150	0.782	17.3	0.150	1.166
	$U[0.5C', 1.0C']$	16.2	0.100	0.310	16.1	0.050	0.721	16.2	0.100	1.402
	$U[1.0C', 4.0C']$	16.1	0.050	0.313	15.9	0.050	0.774	15.8	0.000	1.532
	$U[0.0C', 5.0C']$	16.1	0.150	0.300	15.8	0.000	0.788	15.8	0.000	1.492
	$U[5.0C', 10.0C']$	16.0	0.000	0.311	16.1	0.050	0.733	15.9	0.050	1.493
	$U[10.0C', 20.0C']$	16.2	0.000	0.332	16.1	0.050	0.784	16.1	0.050	1.450
1.0	$U[0.0C', 0.5C']$	16.9	0.150	0.319	16.7	0.250	0.778	17.2	0.100	1.190
	$U[0.5C', 1.0C']$	16.3	0.050	0.293	16.1	0.050	0.679	16.0	0.100	1.482
	$U[1.0C', 4.0C']$	15.9	0.050	0.339	16.0	0.100	0.756	16.0	0.000	1.422
	$U[0.0C', 5.0C']$	16.0	0.100	0.302	15.9	0.050	0.809	15.8	0.000	1.533
	$U[5.0C', 10.0C']$	15.9	0.050	0.336	15.9	0.050	0.776	15.9	0.050	1.481
	$U[10.0C', 20.0C']$	16.0	0.000	0.344	15.9	0.050	0.808	16.1	0.050	1.470
2.0	$U[0.0C', 0.5C']$	16.9	0.150	0.327	17.0	0.100	0.659	16.7	0.050	1.357
	$U[0.5C', 1.0C']$	16.3	0.050	0.310	16.3	0.050	0.696	16.4	0.100	1.359
	$U[1.0C', 4.0C']$	15.9	0.050	0.319	16.0	0.100	0.756	15.9	0.050	1.486
	$U[0.0C', 5.0C']$	15.9	0.050	0.323	15.9	0.050	0.772	15.9	0.050	1.485
	$U[5.0C', 10.0C']$	16.0	0.000	0.303	15.8	0.000	0.840	16.0	0.000	1.443
	$U[10.0C', 20.0C']$	16.0	0.000	0.329	16.1	0.050	0.752	16.0	0.100	1.519
5.0	$U[0.0C', 0.5C']$	16.9	0.150	0.299	16.6	0.100	0.725	17.2	0.100	1.157
	$U[0.5C', 1.0C']$	16.1	0.050	0.295	16.2	0.000	0.676	16.3	0.050	1.311
	$U[1.0C', 4.0C']$	15.9	0.050	0.286	15.8	0.000	0.790	16.0	0.100	1.402
	$U[0.0C', 5.0C']$	15.8	0.000	0.292	15.9	0.050	0.774	16.0	0.000	1.408
	$U[5.0C', 10.0C']$	16.0	0.100	0.333	15.9	0.050	0.797	16.0	0.000	1.424
	$U[10.0C', 20.0C']$	16.1	0.050	0.311	16.0	0.000	0.775	16.0	0.000	1.444
10.0	$U[0.0C', 0.5C']$	16.8	0.100	0.314	16.5	0.250	0.790	17.1	0.150	1.161
	$U[0.5C', 1.0C']$	16.2	0.000	0.289	16.3	0.050	0.719	16.5	0.050	1.269
	$U[1.0C', 4.0C']$	16.0	0.100	0.279	15.9	0.050	0.779	15.8	0.000	1.469
	$U[0.0C', 5.0C']$	15.8	0.000	0.301	15.9	0.050	0.803	15.8	0.000	1.523
	$U[5.0C', 10.0C']$	15.9	0.050	0.310	15.9	0.050	0.792	15.9	0.050	1.473
	$U[10.0C', 20.0C']$	16.1	0.050	0.319	15.9	0.050	0.820	16.0	0.100	1.450

Table 6.33: ILP variants compared on a set of 5 instances with 90 nodes and a density of 0.9 each.

Parameters		OneStepCD			ILP1			ILP2		
RecoloredTT	TabuTenure	<i>obj</i>	<i>sd</i>	<i>time</i>	<i>obj</i>	<i>sd</i>	<i>time</i>	<i>obj</i>	<i>sd</i>	<i>time</i>
0.0	$U[0.0C', 0.5C']$	8.2	0.027	0.095	8.3	0.055	0.247	8.2	0.027	0.678
	$U[0.5C', 1.0C']$	8.2	0.055	0.080	8.1	0.083	0.269	8.1	0.027	0.717
	$U[1.0C', 4.0C']$	7.8	0.000	0.098	7.8	0.000	0.317	7.9	0.027	0.785
	$U[0.0C', 5.0C']$	7.9	0.027	0.091	7.8	0.000	0.318	8.0	0.055	0.750
	$U[5.0C', 10.0C']$	8.0	0.000	0.092	8.0	0.055	0.300	7.9	0.027	0.771
	$U[10.0C', 20.0C']$	8.2	0.000	0.082	8.1	0.027	0.276	8.1	0.000	0.743
0.3	$U[0.0C', 0.5C']$	8.2	0.055	0.083	8.2	0.027	0.259	8.2	0.083	0.677
	$U[0.5C', 1.0C']$	8.2	0.083	0.078	8.1	0.000	0.274	8.2	0.000	0.679
	$U[1.0C', 4.0C']$	8.0	0.055	0.082	7.9	0.027	0.289	7.8	0.000	0.802
	$U[0.0C', 5.0C']$	7.9	0.027	0.091	7.9	0.027	0.292	8.0	0.000	0.749
	$U[5.0C', 10.0C']$	8.0	0.027	0.090	8.0	0.027	0.286	8.0	0.083	0.762
	$U[10.0C', 20.0C']$	8.2	0.055	0.083	8.2	0.027	0.261	8.2	0.055	0.682
0.5	$U[0.0C', 0.5C']$	8.2	0.027	0.080	8.2	0.083	0.273	8.3	0.027	0.667
	$U[0.5C', 1.0C']$	8.1	0.055	0.083	8.0	0.027	0.280	8.1	0.027	0.700
	$U[1.0C', 4.0C']$	7.8	0.000	0.081	7.8	0.000	0.312	7.9	0.027	0.771
	$U[0.0C', 5.0C']$	7.9	0.027	0.093	7.9	0.027	0.293	7.9	0.027	0.772
	$U[5.0C', 10.0C']$	8.0	0.055	0.094	8.0	0.055	0.289	8.1	0.055	0.717
	$U[10.0C', 20.0C']$	8.2	0.027	0.084	8.0	0.027	0.299	8.2	0.055	0.687
1.0	$U[0.0C', 0.5C']$	8.2	0.027	0.081	8.3	0.000	0.261	8.2	0.027	0.675
	$U[0.5C', 1.0C']$	8.2	0.000	0.076	8.2	0.055	0.269	8.1	0.000	0.727
	$U[1.0C', 4.0C']$	7.8	0.000	0.093	7.9	0.027	0.297	8.0	0.027	0.731
	$U[0.0C', 5.0C']$	7.9	0.027	0.090	7.9	0.027	0.300	7.9	0.027	0.786
	$U[5.0C', 10.0C']$	7.8	0.000	0.097	7.9	0.027	0.310	8.0	0.000	0.738
	$U[10.0C', 20.0C']$	8.1	0.027	0.088	8.1	0.055	0.288	8.1	0.027	0.718
2.0	$U[0.0C', 0.5C']$	8.2	0.027	0.079	8.3	0.055	0.251	8.3	0.055	0.666
	$U[0.5C', 1.0C']$	8.1	0.027	0.078	8.0	0.027	0.272	8.2	0.027	0.669
	$U[1.0C', 4.0C']$	7.9	0.027	0.084	7.9	0.027	0.298	7.9	0.027	0.776
	$U[0.0C', 5.0C']$	7.8	0.000	0.089	7.9	0.027	0.294	7.9	0.027	0.767
	$U[5.0C', 10.0C']$	7.9	0.027	0.092	7.9	0.027	0.310	8.1	0.055	0.735
	$U[10.0C', 20.0C']$	8.1	0.027	0.097	8.0	0.000	0.317	8.1	0.000	0.740
5.0	$U[0.0C', 0.5C']$	8.2	0.055	0.083	8.3	0.055	0.247	8.2	0.027	0.685
	$U[0.5C', 1.0C']$	8.1	0.027	0.075	8.1	0.083	0.270	8.2	0.055	0.695
	$U[1.0C', 4.0C']$	7.8	0.000	0.093	7.8	0.000	0.305	8.1	0.055	0.724
	$U[0.0C', 5.0C']$	7.9	0.027	0.091	7.8	0.000	0.318	8.0	0.055	0.760
	$U[5.0C', 10.0C']$	8.0	0.055	0.093	8.1	0.055	0.289	7.8	0.000	0.785
	$U[10.0C', 20.0C']$	8.2	0.055	0.094	8.1	0.000	0.293	8.2	0.055	0.683
10.0	$U[0.0C', 0.5C']$	8.2	0.083	0.080	8.2	0.055	0.271	8.2	0.083	0.700
	$U[0.5C', 1.0C']$	8.1	0.027	0.079	8.1	0.055	0.268	8.1	0.055	0.726
	$U[1.0C', 4.0C']$	7.8	0.000	0.093	8.0	0.083	0.285	8.0	0.055	0.767
	$U[0.0C', 5.0C']$	7.9	0.027	0.104	7.8	0.000	0.302	8.0	0.055	0.770
	$U[5.0C', 10.0C']$	8.0	0.027	0.086	8.0	0.055	0.293	7.9	0.027	0.758
	$U[10.0C', 20.0C']$	8.2	0.055	0.083	8.1	0.027	0.282	8.1	0.027	0.723

Table 6.34: ILP variants compared on a set of 5 instances with 90 nodes and a density of 0.5 each.

Parameters		OneStepCD			ILP1			ILP2		
RecoloredTT	TabuTenure	<i>obj</i>	<i>sd</i>	<i>time</i>	<i>obj</i>	<i>sd</i>	<i>time</i>	<i>obj</i>	<i>sd</i>	<i>time</i>
0.0	$U[0.0C', 0.5C']$	7.6	0.100	0.059	7.5	0.050	0.291	7.9	0.050	0.837
	$U[0.5C', 1.0C']$	7.6	0.100	0.062	7.7	0.050	0.273	7.7	0.150	0.880
	$U[1.0C', 4.0C']$	7.1	0.050	0.073	7.1	0.050	0.326	7.2	0.000	0.958
	$U[0.0C', 5.0C']$	7.1	0.050	0.070	7.2	0.100	0.310	7.3	0.150	0.955
	$U[5.0C', 10.0C']$	7.7	0.050	0.061	7.7	0.050	0.283	7.6	0.000	0.883
	$U[10.0C', 20.0C']$	7.8	0.000	0.059	7.8	0.000	0.263	7.8	0.000	0.840
0.3	$U[0.0C', 0.5C']$	7.8	0.000	0.054	7.8	0.100	0.268	7.5	0.150	0.905
	$U[0.5C', 1.0C']$	7.4	0.100	0.065	7.6	0.100	0.289	7.8	0.000	0.836
	$U[1.0C', 4.0C']$	7.2	0.100	0.080	7.2	0.100	0.307	7.3	0.050	1.002
	$U[0.0C', 5.0C']$	7.4	0.100	0.064	7.4	0.100	0.298	7.4	0.100	0.945
	$U[5.0C', 10.0C']$	7.8	0.000	0.061	7.7	0.050	0.275	7.6	0.000	0.882
	$U[10.0C', 20.0C']$	7.8	0.000	0.059	7.7	0.050	0.279	7.8	0.000	0.811
0.5	$U[0.0C', 0.5C']$	7.8	0.000	0.056	7.5	0.050	0.301	7.5	0.150	0.900
	$U[0.5C', 1.0C']$	7.6	0.100	0.058	7.5	0.150	0.291	7.6	0.100	0.854
	$U[1.0C', 4.0C']$	7.4	0.100	0.071	7.5	0.050	0.293	7.2	0.000	0.993
	$U[0.0C', 5.0C']$	7.2	0.100	0.067	7.2	0.000	0.317	7.2	0.100	0.975
	$U[5.0C', 10.0C']$	7.6	0.100	0.062	7.6	0.100	0.289	7.6	0.000	0.901
	$U[10.0C', 20.0C']$	7.8	0.000	0.062	7.8	0.000	0.280	7.8	0.000	0.881
1.0	$U[0.0C', 0.5C']$	7.5	0.150	0.063	7.5	0.050	0.300	7.6	0.100	0.891
	$U[0.5C', 1.0C']$	7.6	0.100	0.060	7.5	0.150	0.290	7.6	0.100	0.880
	$U[1.0C', 4.0C']$	7.3	0.050	0.072	7.3	0.050	0.311	7.2	0.100	0.974
	$U[0.0C', 5.0C']$	7.3	0.050	0.069	7.3	0.050	0.309	7.3	0.050	0.952
	$U[5.0C', 10.0C']$	7.6	0.000	0.067	7.6	0.100	0.282	7.8	0.000	0.813
	$U[10.0C', 20.0C']$	7.8	0.000	0.062	7.8	0.000	0.276	7.8	0.100	0.822
2.0	$U[0.0C', 0.5C']$	7.4	0.200	0.063	7.8	0.000	0.262	7.3	0.050	0.964
	$U[0.5C', 1.0C']$	7.6	0.100	0.061	7.5	0.150	0.295	7.7	0.050	0.900
	$U[1.0C', 4.0C']$	7.3	0.050	0.069	7.2	0.000	0.331	7.3	0.050	0.931
	$U[0.0C', 5.0C']$	7.1	0.050	0.073	7.4	0.100	0.295	7.1	0.050	1.017
	$U[5.0C', 10.0C']$	7.5	0.150	0.068	7.3	0.150	0.309	7.7	0.050	0.858
	$U[10.0C', 20.0C']$	7.8	0.000	0.062	7.8	0.000	0.259	7.7	0.050	0.857
5.0	$U[0.0C', 0.5C']$	7.5	0.050	0.066	7.6	0.100	0.280	7.8	0.000	0.844
	$U[0.5C', 1.0C']$	7.6	0.100	0.060	7.5	0.150	0.287	7.5	0.150	0.931
	$U[1.0C', 4.0C']$	7.2	0.100	0.068	7.4	0.100	0.293	7.2	0.000	0.946
	$U[0.0C', 5.0C']$	7.6	0.000	0.062	7.4	0.100	0.302	7.2	0.100	0.959
	$U[5.0C', 10.0C']$	7.5	0.050	0.070	7.8	0.000	0.262	7.6	0.100	0.875
	$U[10.0C', 20.0C']$	7.8	0.000	0.063	7.8	0.000	0.275	7.7	0.050	0.863
10.0	$U[0.0C', 0.5C']$	7.7	0.050	0.056	7.7	0.050	0.280	7.8	0.000	0.838
	$U[0.5C', 1.0C']$	7.7	0.050	0.055	7.6	0.100	0.286	7.6	0.100	0.888
	$U[1.0C', 4.0C']$	7.5	0.050	0.063	7.3	0.150	0.306	7.3	0.050	0.963
	$U[0.0C', 5.0C']$	7.2	0.100	0.070	7.3	0.050	0.321	7.0	0.000	1.008
	$U[5.0C', 10.0C']$	7.8	0.000	0.059	7.7	0.050	0.277	7.5	0.050	0.899
	$U[10.0C', 20.0C']$	7.9	0.050	0.061	7.6	0.100	0.288	7.9	0.050	0.822

Table 6.35: ILP variants compared on a set of 5 instances with 100 nodes and a density of 0.5 each.

Parameters		OneStepCD			ILP1			ILP2		
RecoloredTT	TabuTenure	<i>obj</i>	<i>sd</i>	<i>time</i>	<i>obj</i>	<i>sd</i>	<i>time</i>	<i>obj</i>	<i>sd</i>	<i>time</i>
0.0	$U[0.0C', 0.5C']$	8.8	0.000	0.119	8.6	0.000	0.462	8.9	0.050	1.328
	$U[0.5C', 1.0C']$	8.7	0.050	0.119	8.8	0.100	0.435	8.7	0.050	1.392
	$U[1.0C', 4.0C']$	8.6	0.000	0.115	8.6	0.000	0.453	8.6	0.000	1.438
	$U[0.0C', 5.0C']$	8.6	0.000	0.112	8.6	0.000	0.450	8.6	0.000	1.387
	$U[5.0C', 10.0C']$	8.8	0.000	0.116	8.7	0.050	0.448	8.7	0.050	1.400
	$U[10.0C', 20.0C']$	8.8	0.000	0.131	9.0	0.000	0.410	9.0	0.000	1.306
0.3	$U[0.0C', 0.5C']$	8.7	0.050	0.113	8.8	0.100	0.432	8.6	0.000	1.440
	$U[0.5C', 1.0C']$	8.7	0.050	0.119	8.7	0.050	0.446	8.7	0.050	1.395
	$U[1.0C', 4.0C']$	8.6	0.000	0.114	8.6	0.000	0.442	8.6	0.000	1.436
	$U[0.0C', 5.0C']$	8.6	0.000	0.119	8.6	0.000	0.446	8.6	0.000	1.434
	$U[5.0C', 10.0C']$	8.7	0.050	0.127	8.7	0.050	0.452	8.6	0.000	1.438
	$U[10.0C', 20.0C']$	9.0	0.000	0.112	8.9	0.050	0.428	9.0	0.000	1.338
0.5	$U[0.0C', 0.5C']$	9.0	0.000	0.105	8.7	0.050	0.445	8.7	0.050	1.371
	$U[0.5C', 1.0C']$	8.7	0.050	0.117	8.6	0.000	0.442	8.7	0.050	1.407
	$U[1.0C', 4.0C']$	8.6	0.000	0.118	8.6	0.000	0.440	8.6	0.000	1.472
	$U[0.0C', 5.0C']$	8.6	0.000	0.117	8.6	0.000	0.441	8.6	0.000	1.470
	$U[5.0C', 10.0C']$	8.7	0.050	0.125	8.7	0.050	0.442	8.7	0.050	1.421
	$U[10.0C', 20.0C']$	9.0	0.000	0.115	9.0	0.000	0.413	8.8	0.000	1.365
1.0	$U[0.0C', 0.5C']$	8.8	0.000	0.113	8.6	0.000	0.466	8.8	0.000	1.356
	$U[0.5C', 1.0C']$	8.5	0.050	0.136	8.6	0.000	0.453	8.8	0.100	1.353
	$U[1.0C', 4.0C']$	8.6	0.000	0.116	8.6	0.000	0.441	8.6	0.000	1.449
	$U[0.0C', 5.0C']$	8.7	0.050	0.114	8.6	0.000	0.455	8.6	0.000	1.465
	$U[5.0C', 10.0C']$	8.6	0.000	0.126	8.8	0.100	0.436	8.6	0.000	1.417
	$U[10.0C', 20.0C']$	9.0	0.000	0.115	9.0	0.000	0.419	8.9	0.050	1.358
2.0	$U[0.0C', 0.5C']$	8.6	0.000	0.127	8.8	0.100	0.430	8.9	0.050	1.318
	$U[0.5C', 1.0C']$	8.6	0.000	0.120	8.9	0.050	0.408	8.5	0.050	1.443
	$U[1.0C', 4.0C']$	8.6	0.000	0.117	8.6	0.000	0.451	8.6	0.000	1.425
	$U[0.0C', 5.0C']$	8.6	0.000	0.118	8.6	0.000	0.445	8.6	0.000	1.455
	$U[5.0C', 10.0C']$	8.7	0.050	0.121	8.8	0.100	0.428	8.8	0.000	1.349
	$U[10.0C', 20.0C']$	9.0	0.000	0.116	9.0	0.000	0.412	8.9	0.050	1.339
5.0	$U[0.0C', 0.5C']$	8.7	0.050	0.117	8.8	0.100	0.437	8.7	0.050	1.421
	$U[0.5C', 1.0C']$	8.7	0.050	0.116	8.7	0.050	0.442	8.6	0.000	1.410
	$U[1.0C', 4.0C']$	8.6	0.100	0.119	8.6	0.000	0.455	8.6	0.000	1.444
	$U[0.0C', 5.0C']$	8.6	0.000	0.120	8.6	0.000	0.452	8.6	0.000	1.429
	$U[5.0C', 10.0C']$	8.6	0.000	0.125	8.6	0.000	0.464	8.8	0.100	1.394
	$U[10.0C', 20.0C']$	9.0	0.000	0.113	9.0	0.000	0.420	8.9	0.050	1.332
10.0	$U[0.0C', 0.5C']$	8.7	0.050	0.115	8.8	0.100	0.423	8.8	0.000	1.343
	$U[0.5C', 1.0C']$	8.7	0.050	0.117	8.7	0.050	0.429	8.6	0.000	1.410
	$U[1.0C', 4.0C']$	8.6	0.000	0.115	8.6	0.000	0.452	8.6	0.000	1.426
	$U[0.0C', 5.0C']$	8.6	0.000	0.115	8.6	0.000	0.455	8.6	0.000	1.430
	$U[5.0C', 10.0C']$	8.6	0.000	0.132	8.8	0.000	0.434	8.6	0.000	1.439
	$U[10.0C', 20.0C']$	9.0	0.000	0.114	9.0	0.000	0.419	9.0	0.000	1.284

Table 6.36: ILP variants compared on a set of 5 instances with 120 nodes and a density of 0.5 each.

Comparison to previous works

Since *RANDOM* performs best in terms of runtime and is not significantly inferior to other methods in terms of quality, its results are compared to those of [3] and [6] in tables 6.37 and 6.38. In 6.39 results are compared to [5].

Instance set		B & C		Random (10 runs/inst)			MA2		
nodes	density	LB	UB	\overline{obj}	sd	$time(s)$	\overline{obj}	sd	$time(s)$
20	0.5	3	3	3.00	0.00	0.01	3.00	0.00	0.14
40	0.5	4	4	4.00	0.00	0.02	4.00	0.00	0.60
60	0.5	5	5	5.00	0.00	0.06	5.63	0.49	2.00
70	0.5	6	6	6.00	0.00	0.08	6.06	0.24	3.33
80	0.5	6	6	6.27	0.13	0.15	6.94	0.29	4.90
90	0.5	6	7	7.88	0.17	0.36	7.55	0.50	7.49
100	0.5	6	7	7.12	0.01	0.32	7.93	0.30	11.04
120	0.5	7	8	8.64	0.19	0.52	9.22	0.43	21.05

Table 6.37: TODO

Instance set		B & C		Random (10 runs/inst)			MA2		
nodes	density	LB	UB	\overline{obj}	sd	$time(s)$	\overline{obj}	sd	$time(s)$
90	0.1	2	3	3.00	0.00	0.02	3.09	0.29	1.37
90	0.2	3	4	3.80	0.15	0.03	4.41	0.49	3.24
90	0.3	4	5	5.00	0.00	0.06	5.52	0.56	4.90
90	0.4	5	6	6.00	0.00	0.11	6.79	0.83	6.54
90	0.5	6	7	7.00	0.00	0.18	7.55	0.50	7.49
90	0.6	8	8	8.28	0.15	0.31	10.50	0.87	11.95
90	0.7	10	10	10.00	0.00	0.45	12.39	1.12	14.83
90	0.8	12	12	12.05	0.14	0.80	15.18	0.80	20.98
90	0.9	16	16	15.80	0.15	1.23	17.27	0.98	45.75

Table 6.38: pcpn120

Parameters		DSJC500.5-1		DSJC500.5-2		DSJC500.5-3		DSJC500.5-4	
ItMax	TabuTenure	Random	Noronha	Random	Noronha	Random	Noronha	Random	Noronha
1	$U[0.25C', 0.75C']$	53.0	53.5	47.6	47.8	45.0	44.8	43.4	43.5
	$U[0.0C', 1.0C']$	53.0	53.7	47.0	47.5	45.0	45.4	43.2	43.6
	$U[0.0C', 0.5C']$	52.0	53.1	47.0	47.3	45.0	44.6	44.0	42.8
	$U[0.5C', 1.0C']$	52.6	54.2	47.2	48.1	45.0	45.8	43.0	43.9
	$U[0.25C', 1.0C']$	53.0	53.8	47.2	47.9	45.0	45.5	43.6	43.6
	$U[0.0C', 0.75C']$	52.4	53.3	47.6	47.5	45.0	44.8	43.6	43.0
5	$U[0.25C', 0.75C']$	52.0	52.7	47.0	46.8	44.0	44.4	43.0	42.8
	$U[0.0C', 1.0C']$	51.4	52.9	47.0	46.8	44.0	44.7	42.4	42.7
	$U[0.0C', 0.5C']$	51.4	52.2	47.0	46.1	44.0	43.7	43.0	42.0
	$U[0.5C', 1.0C']$	52.0	53.3	47.0	47.7	44.4	44.9	43.0	43.0
	$U[0.25C', 1.0C']$	51.4	53.0	47.0	47.3	44.8	44.7	43.0	42.9
	$U[0.0C', 0.75C']$	52.0	52.5	47.0	46.6	44.6	44.0	43.0	42.4
10	$U[0.25C', 0.75C']$	51.0	52.5	47.0	46.7	44.0	44.0	43.0	42.4
	$U[0.0C', 1.0C']$	51.0	52.3	46.4	46.7	44.0	44.2	43.0	42.7
	$U[0.0C', 0.5C']$	51.0	51.3	47.0	45.9	44.0	43.3	43.0	42.0
	$U[0.5C', 1.0C']$	51.0	53.0	47.0	47.3	44.6	44.8	42.8	43.0
	$U[0.25C', 1.0C']$	51.8	52.8	46.4	46.9	44.0	44.2	43.0	42.8
	$U[0.0C', 0.75C']$	51.0	52.2	47.0	46.2	44.0	43.9	43.0	42.2

Table 6.39: in1

Summary

The PCP is a quite recently proposed COP which generalizes the classical VCP by considering the possibility to select subsets of nodes. While for the VCP much research has been done, only a few papers about the PCP has been published so far. In this work a strategy is presented that creates an initial solution by a heuristical algorithm and improves the solution quality by recoloring sets of nodes of same color before eliminating the resulting conflicts by applying a tabu search. It has been tried to enhance the algorithm presented in [5] by substituting the process of random recoloring by more sophisticated algorithms in order to minimize the number of resulting conflicts. A variation of the *ONESTEP*CD algorithm [4] and two ILPs were used. A local search algorithm then tries to eliminate all these conflicting nodes to create a feasible solution. Furthermore experiments with variations of the ILPs and a mechanism that – on order to protect a recolored subgraph from being overwritten – puts that subgraph on the tabulist for an amount of iteration.

The results have shown that more sophisticated recoloring algorithms can reduce the number of conflicts dramatically. For the instances used, a random recoloring produces an amount of conflicting nodes up to 7.5 times higher than an optimized recoloring does. The fact that that gap is not reflected significantly in the final results leads to the conclusion that for the presented strategy the tabu search is much more relevant than the recoloring process.

7.1 Critical Reflection

Selecting and optimizing the coloring of a subset of clusters regardless of their location in the graph does not tackle the problem in an efficient way. The selection does not take into account any features of the graph like regional density, although dense subgraphs involve the most danger of increasing the chromatic number by a suboptimal coloring. Considering graph features being crucial for a good selection of clusters, the selection presented in this thesis is done in a random way and therefore an optimal, partial recoloring can not be integrated in the solution more probably than a random coloring.

7.2 Future Works

Future works could consider a more suggestive selection of the clusters to be recolored. Rather than selecting all clusters of the same color, the set could be chosen by criteria of regional density. Putting effort in optimizing these regions – e.g. by the use of exact methods – could lead to results of higher quality.

Algorithm 1: PCP HYBRID DENSERECOLORING

Input: An uncolored Graph $G = (V, E)$, a recoloring-algorithm *RECOLOR*, two integers *maxSubgraphs* and *denseMaxSize*

Output: A feasible Solution S

- 1 Set $S \leftarrow \text{ONESTEP CD}(G)$;
- 2 Set $cmax \leftarrow$ the chromatic number of S ;
- 3 Set $D \leftarrow \text{FINDDENSESUBGRAPHS}(S, \text{maxSubgraphs}, \text{denseMaxSize})$;
- 4 Let R be the set of all remaining nodes in V colored with $cmax$;
- 5 Let S' be the solution after recoloring R randomly and all subgraphs in D with *RECOLOR*;
- 6 Let C' be the set of nodes involved into color conflicts in S' ;
- 7 Set $C_c \leftarrow C \setminus V_c$;
- 8 $S' \leftarrow \text{TABU SEARCH}(S', D \cup R, C')$;
- 9 **if** S' is free of conflicts **then**
- 10 $S \leftarrow S_c$;
- 11 $cmax = cmax - 1$;
- 12 **goto** line 3;
- 13 **return** S ;

Bibliography

- [1] M. Templ B.Meindl. Analysis of commercial and free and open source solvers for linear optimization problems. 2012.
- [2] C.Volko. Selective graph coloring problem. 2012.
- [3] Yuri Frota, Nelson Maculan, Thiago F. Noronha, and Celso C. Ribeiro. A branch-and-cut algorithm for the partition coloring problem. *Networks*, 55(3):194–204, 2010.
- [4] Guangzhi Li and Rahul Simha. The partition coloring problem and its application to wavelength routing and assignment. In *1st Workshop on Optical Networks*, 2000.
- [5] Thiago F. Noronha and Celso C. Ribeiro. Routing and wavelength assignment by partition colouring. *European Journal of Operational Research*, 171(3):797–810, 2006.
- [6] Petrica C. Pop, Bin Hu, and Günther R. Raidl. A memetic algorithm for the partition graph coloring problem. In *Extended Abstracts of the 14th International Conference on Computer Aided Systems Theory*, pages 167–169, Gran Canaria, Spain, 2013.