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Kurzfassung

In der vorliegenden Arbeit werden heuristische und metaheuristische Lösungsalgorithmen für das Hop Constrained Node Survivable Network Design Problem (HNSND) und das Hop Constrained Edge Survivable Network Design Problem (HESND) präsentiert und miteinander verglichen.

Hop Constrained Survivable Network Design ist ein *NP*-schweres Problem. Nachdem die Lösung in der vorliegenden Arbeit als Subgraph repräsentiert wird, ist bereits der Test, ob eine Lösung gültig ist, *NP*-schwer. Daher liegt der erste Schwerpunkt der Arbeit auf der Entwicklung eines fortgeschrittenen Tests, welcher in polynomieller Zeit zumindest ungültige Lösungen ausschließen kann, dies am besten mit einer sehr kleinen Fehlerrate, um die Anwendungen des zeitintensiven exakten Gültigkeitstest zu minimieren. Die Ergebnisse auf den getesteten Instanzen zeigen, dass der polynomielle "Advanced Check" eine Fehlerrate von rund 1% in Bezug auf "False Positives" hat, mit anderen Worten rund 1% der durchgelassenen Lösungen keine gültige Lösung darstellen. Darüber hinaus liegt der Algorithmus insgesamt in rund 0,40% aller getesteten Instanzen mit seiner Bewertung falsch.

Danach werden 27 verschiedene Lösungsalgorithmen entwickelt, darunter zehn Konstruktionsheuristiken, zehn Variable Neighborhood Descent (VND) Varianten, sechs Multi-Start VND Varianten, sowie ein Greedy Randomized Adaptive Search Procedure Ansatz. Weiters wird ein verbesserter exakter Gültigkeitstest präsentiert. Die Ergebnisse auf den getesteten Instanzen zeigen, dass einige Verfahren optimale Ergebnisse erzielen. Überblicksmäßig ergibt sich für das HESND im Schnitt eine Abweichung von 5-25% von der Optimallösung, für das HNSND gibt es keine Vergleichswerte auf den getesteten Instanzen.

Zusammenfassend ist zu sagen, dass die vorliegende Arbeit eine große Toolbox an heuristischen Methoden für Hop Constrained Survivable Network Design Probleme präsentiert, welche gute Resultate in vernünftiger Zeit erzielen.

Abstract

In this thesis, heuristic and meta-heuristic algorithms for solving the Hop Constraind Node Survivable Network Design Problem (HNSND) and the Hop Constrained Edge Survivable Network Design Problem (HESND) are presented and compared to each other.

Hop constrained survivable network design is an *NP*-hard problem. Since solutions are encoded as subgraphs in this thesis, the feasibility test is *NP*-hard too. Hence, the first main focus is developing a (fast) advanced feasibility check, which checks in polynomial time that at least a given solution provably is not feasible, at best with a very small error rate, in order to minimize applications of the time-consuming exact feasibility test. Computational results show that this polynomial-time advanced feasibility check has an error rate of about 1% regarding "false positives" and furthermore this algorithm has a total error rate of about 0,40% over all tested instances.

In the following, 27 different problem solution algorithms are developed, including ten constructive heuristic variants, ten Variable Neighborhood Descent (VND) variants, six Multi-Start VND variants and a Greedy Randomized Adaptive Search Procedure approach. In addition, an improved exact feasibility test is introduced. Computational results show that some solution methods meet the optimal results regarding the edge-disjointness variant. On a general view, the best approaches yield a gap of about 5-25% on average. Regarding the node-disjointness variant there are no comparable results for the test instance sets.

Finally, it can be said that this thesis provides a big toolbox of heuristic methods for solving hop constrained network design problems, which yield good results in a reasonable amount of time.

Contents

Chapter 1

Introduction

1.1 Network design with survivability and hop constraints

Network design is a "hierarchical decision making process" [66] in the planning phase of network construction. The aim is a good topological design, where good means a solution that satisfies all of the imposed requirements and has minimum costs. These requirement are often called constraints. We deal here with two requirements which reflect the needs imposed on modern networks, namely survivability and quality of service.

Network survivability is defined as "the ability of a network to maintain its communication capabilities in the face of equipment failure" [75]. Failures can occur when the communication links (e.g. cables) fail or important network facilities (e.g. switches, routing facilities such as base stations, satellites, ...) break down. As networks can be represented by graphs, survivability is ensured by demanding two or more disjoint paths between a given pair of nodes. Disjointness comes in two variants: When we want to cover only the failure of communication links, we demand edge-disjointness. When we furthermore want to cover the case of essential network facilities breaking down, then we demand node-disjointness. The latter of course includes the former, so in this case of node-disjointness the failure of communication links is covered too. For most of the networks two disjoint paths between given nodes suffice, ensuring survivability in case one single facility or link fails. But some networks (e.g. military or high security) even demand survivability in case that two or more facilities or links fails. Therefore the number of disjoint paths must be higher. With K disjoint paths we can cover the failure of $K-1$ facilities or links. Survivability has become a major issue in the design of networks over the last decades because, due to the high capacity of modern telecommunication cables (fiber-optic), networks tend to get more sparse than before.

Quality of service of a network can e.g. be measured in the time a packet in a network needs to get from its source to its destination. It is often more time consuming to decide on which links a packet must be routed than the actual "travel time“ on a link. To ensure quality of service one seeks to minimize the number of nodes which are passed between source and destination. Therefore only paths are considered which do not exceed a given number of links. This is denoted as the hop limit.

So the Hop Constrained Survivable Network Design Problem arises at the design of networks, which should meet the requirements, we nowadays put on reliable and effective networks.

1.2 Outline of the thesis

The thesis is organized as follows.

As networks can be represented by graphs, Chapter 2 first gives a brief overview on the basic concepts and definitions from graph theory which we need for this representation, i.e. the formal definition, and the developing of good solution techniques for the Hop Constrained Survivable Network Design Problem. Then follows a short survey on the related works on survivable network design, hop constraints and a combination of these, as well as works done on arising subproblems and related problems. Chapter 2 concludes with some remarks on the complexity of the Hop Constrained Network Design Problem.

In Chapter 3, we present algorithms for preprocessing the network, i.e. determining the structural information of a graph like components, blocks and cutpoints. Moreover, algorithms are developed for transforming graphs - so we can solve edge-disjointness requirements with an algorithm for node-disjointness and vice versa - and testing feasibility of a solution, given as a subgraph or a set of paths. Furthermore algorithms are presented, which heuristically solve the single commodity case.

In Chapter 4, we present four constructive heuristics. These heuristics produce initial solutions we can then use for the metaheuristic approaches.

In Chapter 5, we present the metaheuristic approaches for the Hop Constrained Survivable Network Design Problem. At first we present a Variable Neighborhood Descent (VND) with two neighborhoods. This neighborhoods are called Recalculate Commodity Neighborhood (RCN) and Key-Path Exchange Neighborhood (KPEN). Then the VND is used in a multi-start approach, where we make use of the randomization possibility of CH3 and CH4. Last, but not least, a Greedy Randomized Adaptive Search Procedure (GRASP) is presented, where the greedy CH1 is randomized and afterwards the VND is applied to improve the solution value given by the randomized greedy constructive heuristic.

In Chapter 6, we shortly discuss the implementation and the instance sets. Furthermore, we present result tables for all implemented solution algorithms, as well as results regarding the different feasibility test methods. Comprehensive and detailed result tables can be found in Appendix A. Moreover, the computational results are discussed.

In Chapter 7, the thesis closes with the concluding remarks.

Chapter 2

Problem definition

Although there has been much work done on survivability issues in networks and hop constraints, the notation is by no means unified. For this reason we will build our formal definition of the Hop Constrained Survivable Network Design Problem from scratch.

As networks can be represented by graphs, we first give a brief overview on the basic concepts and definitions from graph theory which we need for this representation, i.e. the formal definition, and the developing of good solution techniques for the Hop Constrained Survivable Network Design Problem. Then we give a short survey on the related works on survivable network design, hop constraints and a combination of these, as well as works done on arising subproblems and related problems. The chapter concludes with some remarks on the complexity of the Hop Constrained Network Design Problem.

2.1 Basic concepts and definitions from graph theory

This section gives a brief overview on the basic concepts and definitions from graph theory which will be needed for the analysis of the Hop Constrained Survivable Network Design Problem. More detailed introductions into graph theory can be found in [3, 17, 18, 20, 27, 48, 50, 68, 83]. Furthermore we will introduce the notation that is consistently used in the thesis.

2.1.1 Graphs, subgraphs, paths

Definition 2.1 (Graph). *A graph is a tuple $G = (V, E)$, where V denotes the set of nodes and $E \subseteq V \times V$ denotes the set of edges. An edge from node i to j is denoted by $\{i, j\}$. We call a graph simple, if it does not contain multiple edges, i.e. more than one edge between the same nodes, or loops, i.e. edges $\{i, i\}$.*

Definition 2.2 (Directed graph). *A directed graph or digraph is a tuple $D = (V, A)$, where V denotes the set of nodes and $A \subseteq V \times V$ denotes the set of arcs or directed edges. An arc from node i to j is denoted by (i, j). We call a directed graph simple, if it does not contain multiple arcs, i.e. more than one arc between the same nodes, or loops, i.e. arcs (i, i).*

When in the following it is clear from the context if we mean directed or undirected graphs or if it makes no difference, we will for simplicity just speak of graphs. Furthermore we consider only simple graphs, unless explicitly stated otherwise.

Definition 2.3 (Complete graph). *A complete graph is a simple graph with a maximal number of edges, i.e. $|E| = \frac{|V| \cdot (|V|-1)}{2}$. A complete graph with n nodes is denoted by K_n.*

Definition 2.4 (Complement). *The complement of a graph $G = (V, E)$ is defined as $C(G) = (V_C, E_C)$, where $V_C = V$ and $E_C = (V \times V) \setminus E$, so the complement contains all the nodes of G and all edges that are not in G.*

Definition 2.5 (Subgraph). *Given a graph $G = (V, E)$, $G' = (V', E')$ is called a subgraph if $V' \subseteq V$, $E' \subseteq E$ and $E' \subseteq V' \times V'$. If $V' = V$ we call G' a spanning subgraph or factor.*

Definition 2.6 (Deletion of an edge). *Given a graph $G = (V, E)$, $G - e = (V, E \setminus e)$.*

Definition 2.7 (Deletion of an node). *Given a graph $G = (V, E)$, $G - v = (V \setminus v, E \setminus \{e \mid v \in e\})$.*

Definition 2.8 (Adjacency and incidence). *Two nodes x and y are called adjacent, if they share an edge e, i.e. $\exists e = \{x, y\} \in E$. Two edges e and f are called adjacent, if they share a node x, i.e. $e \cap f = x$. A node v is called incident to an edge e, if $v \in e$.*

Definition 2.9 (Node degree). *The degree of a node v in an undirected graph*

G, denoted by $d(v)$, is the number of edges, that are incident to the node v, i.e. in E there exists an edge $\{v, x\}$. The number of outgoing arcs (v, x) from a node v in a directed graph D is called out-degree and is denoted by $d^+(v)$, the number of ingoing arcs (x, v) to a node v is called in-degree and is denoted by $d^-(v)$.

Lemma 2.10 (Handshaking Lemma)**.**

$$\sum_{v \in V} d(v) = 2 \cdot |E|$$

Proof. As every edge $\{i, j\}$ is incident to exactly two nodes, namely i and j, it is counted one time at $d(i)$ and one time at $d(j)$. So the sum over all node degrees is exactly two times the number of edges. □

Corollary 2.11. *The number of nodes with odd node degree is even.*

Proof. This immediately follows from the handshaking lemma. □

Lemma 2.12.

$$\sum_{v \in V} d^+(v) = \sum_{v \in V} d^-(v) = |A|$$

Proof. As every arc (i, j) has exactly one "in-node" and one "out-node", it follows, that the sum of all out-degrees equals the sum of all in-degrees and hence the number of arcs. □

Definition 2.13. *$\Delta(G) = max\{d(v) \mid v \in V\}$ denotes the maximum node degree in a graph. $\delta(G) = min\{d(v) \mid v \in V\}$ denotes the minimum node degree in a graph.*

Definition 2.14 (Neighborhood of a node)**.** *The neighborhood of a node $v \in V$ is denoted by $N(v) = \{x \mid \{v, x\} \in E\}$. In the directed case the neighborhood consists of all nodes that are reachable from v, i.e. $N(v) = \{x \mid (v, x) \in A\}$.*

Definition 2.15 (Walk)**.** *A sequence $v_0, e_1, v_1, e_2, ...e_n, v_n$ with $n \geq 0$ is called a walk, if for all v_i with $i \neq 0$ exists an $e_i = \{v_{i-1}, v_i\} \in E$.*

Definition 2.16 (Directed walk)**.** *A sequence $v_0, a_1, v_1, a_2, ...a_n, v_n$ with $n \geq 0$ is called a directed walk, if for all v_i with $i \neq 0$ exists an $a_i = (v_{i-1}, v_i) \in A$.*

Definition 2.17 (Trail)**.** *A sequence $v_0, e_1, v_1, e_2, ...e_n, v_n$ with $n \geq 0$ is called a trail, if for all v_i with $i \neq 0$ exists an $e_i = \{v_{i-1}, v_i\} \in E$ and all e_i are distinct.*

Definition 2.18 (Directed trail). *A sequence $v_0, a_1, v_1, a_2, ...a_n, v_n$ with $n \geq 0$ is called a directed trail, if for all v_i with $i \neq 0$ exists an $a_i = (v_{i-1}, v_i) \in A$ and all a_i are distinct.*

Definition 2.19 (Path). *A sequence $v_0, e_1, v_1, e_2, ...e_n, v_n$ with $n \geq 0$ is called a path, if for all v_i with $i \neq 0$ exists an $e_i = \{v_{i-1}, v_i\} \in E$ and all v_i are distinct.*

Definition 2.20 (Directed path). *A sequence $v_0, a_1, v_1, a_2, ...a_n, v_n$ with $n \geq 0$ is called a directed path, if for all v_i with $i \neq 0$ exists an $a_i = (v_{i-1}, v_i) \in A$ and all v_i are distinct.*

When in the following it is clear from the context if we mean directed or undirected walks/trails/paths or if it makes no difference, we will for simplicity just speak of walks/trails/paths.

Definition 2.21 (Length of a path). *Given a path $P = v_0, e_1, v_1, e_2, ...e_n, v_n = P(v_0, v_n)$, the length is the number of edges and denoted by $l(P) = n$, analogously for the directed case.*

Definition 2.22 (Cycle). *A cycle is a path, where $v_0 = v_n$.*

Theorem 2.23. *Let $W = W(v_0, v_n)$ be a walk, then there is a subsequence $P = P(v_0, v_n) \subseteq W(v_0, v_n)$ such that P is a path.*

Proof. We know that for a path holds $v_i \neq v_j \ \forall \ i < j$. Suppose for W holds that $v_i = v_j$ for arbitrary $i < j$. Then $W' = v_0, e_1, v_1, ..., v_i, e_{j+1}, v_{j+1}, ..., v_n$ is a walk with $i - j$ less edges and W' is a subsequence of W. Applying this until $\forall i, j : v_i \neq v_j$ yields a path from v_0 to v_n. This of course also holds for the directed case. □

From Theorem 2.23 follows that dealing with paths suffices when we want to draw conclusions about a connection between two nodes.

2.1.2 Trees, graph structure

Definition 2.24 (Acyclic graph). *A graph is called acyclic if it does not contain a cycle.*

Definition 2.25 (Connectedness). *A graph $G = (V, E)$ is called connected if $\forall x, y \in V \ \exists P(x, y)$. A directed graph D is called strongly connected if for all $x, y \in V$ there exists a directed path $P(x, y)$ and a directed path $P(y, x)$. A directed* *graph D is called weakly connected if the underlying graph G (where all the arcs are transformed to edges) is connected.*

Definition 2.26 (Component). *Let $G_1, G_2, ..., G_r$, $r \geq 1$, be the maximally connected subgraphs of G, they are called components. Hence, $G = \bigcup_{i=1}^{r} G_i$. This disjoint union is unique.*

Definition 2.27 (Forest). *A forest $F = (V, E)$ is a graph which is acyclic.*

Definition 2.28 (Tree). *A tree $T = (V, E)$ is a graph which is acyclic and connected.*

Definition 2.29 (Spanning tree). *A graph $G' \subseteq G$ is called a spanning tree if it is a spanning subgraph which is a tree.*

Proposition 2.30. *A graph G is connected $\iff$ G contains a spanning tree.*

Proof. The direction $\Leftarrow$ is easy to show: By adding edges to a spanning tree, it can not lose its connectedness. The other direction is also easy to show: Let $e \in E$ be an edge that is contained in a cycle. By deleting this edge, the graph is still connected. By inductively deleting edges contained in a cycle we in the end get a graph that is connected and acyclic, thus a tree $T \subseteq G$. As we have not deleted any nodes, T is a spanning tree. $\square$

Theorem 2.31. *G is a tree $\iff$ G is connected and $|V| = |E| + 1$.*

Proof. See e.g. the proof in [50]. $\square$

Definition 2.32 (Cutpoint). *Given a graph $G = (V, E)$, a node $v \in V$ is called cutpoint, if $G - v$ has more components than G.*

Definition 2.33 (Bridge). *Given a graph $G = (V, E)$, an edge $e \in E$ is called bridge, if $G - e$ has more components than G.*

Definition 2.34 (Nonseparability). *A connected graph $G = (V, E)$ is called nonseparable, if $G - v$ is still connected $\forall v \in V$.*

Definition 2.35 (Block). *Given a graph $G = (V, E)$, the blocks of G are the maximally nonseparable subgraphs of G. Blocks are sometimes also called biconnected components.*

Definition 2.36 (Block-Cutpoint-Graph). *Given a graph $G = (V, E)$, the block-cutpoint-graph is denoted by $bc(G) = (V_{bc}, E_{bc})$, where $V_{bc} = \{B_i \mid B_i$ is a* *block of* $G\} \cup \{v \in V \mid v$ *is a cutpoint in* $G\}$ *and* $E_{bc} = \{e = \{x, y\} \mid x$ *is a block of* G *and* y *is a cutpoint of* G *and* $y \in V_x\}$.

Proposition 2.37. *G is connected $\Longleftrightarrow$ $bc(G)$ is a tree.*

Proof. The direction $\Leftarrow$ is easy to show: Assume $bc(G)$ is a tree, then it is connected. Therefore also the graph G must by Definition 2.36 be connected.

Now we have to show the other direction:

Assume $bc(G)$ is not connected. Then we have at least two components. Let the first component be G_1, and $G_2 = bc(G) \setminus V_{G_1}$ be the rest. Consider a block $B_1 \subseteq G_1$ and a block $B_2 \subseteq G_2$. Now look at arbitrary $x \in V_{B_1}$ and $y \in V_{B_2}$. As G is connected by assumption, there must be a path from x to y in G. So $P_G(x, y) = P_G(x, z_1), P_G(z_1, z_2), ..., P_G(z_k, y)$, $k \geq 1$ and all z_i are cutpoints of G. Hence the same path looks in $bc(G)$ like this: $P_{bc(G)}(B_1, B_2) = B_1, z_1, z_2, ..., z_k, B_2$, which is a contradiction to the assumption that B_1 and B_2 lie in different components of $bc(G)$. Therefore $bc(G)$ is connected.

Now assume $bc(G)$ contains a cycle $C = B_1, z_1, B_2, z_2, ..., B_k, z_k, B_1$ and w.l.o.g. let $l(C)$ be minimal. As $l(C)$ is minimal, it follows that $B_i \cap B_j \neq \emptyset \Leftrightarrow j = i \pm 1 \mod k$. We know that $P_i(z_{i-1}, z_i) \subseteq B_i$. So the cycle $C = P_1(z_k, z_1), P_2(z_1, z_2), ..., P_k(z_{k-1}, z_k) \subseteq G$. As C is a cycle in G, it is a nonseparable subgraph of G and therefore $C \subseteq B$, where B is a block of G. It follows that $E_B \cap E_{B_i} \neq \emptyset \; \forall i = 1, ..., k$. This contradicts the assumption that $l(C)$ is minimal. Therefore $bc(G)$ does not contain any cycle.

As $bc(G)$ is connected and acyclic, it follows from Definition 2.28 that $bc(G)$ is a tree. □

2.1.3 Connectivity

Theorem 2.38. *If G is not connected, the complement $C(G)$ is connected.*

Proof. Let G be a not connected graph and consider two arbitrary nodes v_1 and v_2. If v_1 and v_2 are not in the same component, then in the complement they are connected (they are even adjacent). If v_1 and v_2 are in the same component, consider an arbitrary node u in another component, since G is not connected this node u must exist. Then in the complement v_1 and v_2 are still connected. Since v_1 and v_2 are arbitrary nodes, $C(G)$ is connected in both cases. □

Corollary 2.39. *There are more connected graphs than there are not connected graphs.*

Proof. This follows from Theorem 2.38: As the complement of a not connected graph is connected and the complement of a connected graph can be connected too (consider for example a connected graph with four nodes and three edges and its complement), the number of connected graphs is higher than the number of not connected graphs. □

Definition 2.40 (Local node connectivity). *The local node connectivity $\kappa(x, y)$ between two non adjacent nodes x and y is the minimum number of nodes, which have to be deleted such that in the resulting graph there is no more path from x to y.*

Definition 2.41 (Global node connectivity). *The global node connectivity of a graph is $\kappa(G) = min\ \kappa(x, y),\ \forall x, y \in V, e = \{x, y\} \notin E$.*

Definition 2.42 (K-node connectivity). *We call a graph K-node connected, if $\kappa(G) \geq K$.*

Definition 2.43 (Separating vertex set). *Given two non adjacent nodes x and y, a set $S \subset V$ is called a separating vertex set, if every $P(x, y)$ has at least one node in S.*

Definition 2.44 (Node disjoint paths). *The maximum number of pairwise node disjoint paths, i.e. paths that share no node except the start node and the end node, between two nodes is denoted by $\rho(x, y)$.*

Corollary 2.45. *$\rho(x, y) \leq |S|$ for all non adjacent nodes x and y.*

Proof. It is easy to see, that the cardinality of S must be at least as big as the number of pairwise node disjoint paths. □

Theorem 2.46 (Menger's Theorem). *Given a graph $G = (V, E)$ and two non adjacent nodes x and y, $\rho(x, y) = \kappa(x, y)$ holds.*

Proof. See [30]. □

Theorem 2.47 (Whitney's Theorem). *Given a K-node connected graph $G = (V, E) \iff \forall x, y \in V\ \exists K$ pairwise node disjoint paths from x to y.*

Proof. Assume G is K-node connected, then by Definition 2.42 $K \leq \kappa(G) = \min \kappa(x, y)$. From Theorem 2.46 follows that $K \leq \rho(x, y)$, therefore there are at least K pairwise node disjoint paths from x to y. Now the other direction: By Definition 2.41 $\kappa(G) = \min \kappa(x, y)\ \forall x, y \in V, e = \{x, y\} \notin E$. From Theorem 2.46 follows that $\kappa(G) = \min \rho(x, y)\ \forall x, y \in V, e = \{x, y\} \notin E$, which denotes the K

pairwise node disjoint paths from x to y. Hence, $\kappa(G) \geq K$ and by Definition 2.42 G is K-node connected. □

Definition 2.48 (Local edge connectivity). *The local edge connectivity $\lambda(x, y)$ between two nodes x and y is the minimum number of edges, which have to be deleted such that in the resulting graph there is no more path from x to y.*

Definition 2.49 (Global edge connectivity). *The global edge connectivity of a graph is $\lambda(G) = min\ \lambda(x, y),\ \forall x, y \in V, e = \{x, y\} \notin E$.*

Definition 2.50 (K-edge connectivity). *We call a graph K-edge connected, if $\lambda(G) \geq K$.*

Definition 2.51 (Separating edge set). *Given two nodes x and y, a set $S_e \subset V$ is called a separating edge set, if every $P(x, y)$ has at least one edge in S_e.*

Definition 2.52 (Edge disjoint paths). *The maximum number of pairwise edge disjoint paths, i.e. paths that share no edge, between two nodes is denoted by $\rho_e(x, y)$.*

Corollary 2.53. *$\rho_e(x, y) \leq |S_e|$ for all non adjacent nodes x and y.*

Proof. It is easy to see, that the cardinality of S_e must be at least as big as the number of pairwise edge disjoint paths. □

Theorem 2.54 (Menger's Theorem, edge version). *Given a graph $G = (V, E)$ and two nodes x and y, $\rho_e(x, y) = \lambda(x, y)$ holds.*

Proof. This proof can be obtained by the Max-Flow-Min-Cut Theorem [28, 31, 32], see e.g. [50], or with the help of Theorem 2.46 [30]. □

Theorem 2.55 (Whitney's Theorem, edge version). *Given a K-edge connected graph $G = (V, E) \iff \forall x, y \in V\ \exists K$ pairwise edge disjoint paths from x to y.*

Proof. The proof is similar to the proof of Theorem 2.47 using Theorem 2.54. □

Finally, we present some useful corollaries, without proof because they are obvious.

Corollary 2.56. *Given a graph $G = (V, E)$ and two non adjacent nodes x and y, then $\kappa(G) \leq \kappa(x, y) \leq \Delta(G)$.*

Corollary 2.57. *Given a graph $G = (V, E)$, then $\kappa(G) \leq \delta(G)$.*

Corollary 2.58. *Given a graph $G = (V, E)$, then $\lambda(G) \leq \lambda(x, y) \leq \Delta(G)$.*

Corollary 2.59. *Given a graph $G = (V, E)$ and two non adjacent nodes x and y, then $\kappa(x, y) \leq \lambda(x, y) \leq min\{d(x), d(y)\}$.*

Corollary 2.60. *Given a graph $G = (V, E)$, then $\kappa(G) \leq \lambda(G) \leq \delta(G)$.*

2.2 Formal problem definition

Based on the definitions and results from the last section we can now build our formal definition of the Hop Constrained Survivable Network Design Problems. We will deal with tree different variants, for each of these we give one definition regarding the edge-disjointness and another definition regarding node-disjointness. We do not need to restrict ourselves to either the node-disjoint or the edge-disjoint case: In Chapter 3 we will present polynomial-time graph transformation algorithms which allow solving the node-disjoint version with an algorithm for edge-disjointness and vice versa.

Before we can formally define the problems, we need two more definitions.

Definition 2.61 (Network). *A network $N = (G, c)$ consists of a graph $G = (V, E)$ and a cost function $c : E(G) \longrightarrow \mathbb{R}_{\geq 0}$, which assigns each edge e a nonnegative value c_e. Networks are also called weighted graphs.*

Definition 2.62 (Cost of a graph). *The cost c_G of a graph G is the sum of its edge costs, i.e. $c_G = \sum_{e \in E} c_e$.*

For all three versions, we define the notion of a commodity, which models the constraints for survivability and hoplimits between two given vertices.

2.2.1 Basic version

The basic version of the Hop Constrained Survivable Network Design Problem has only the constraints outlined in Chapter 1, i.e. the survivability constraint and the hop constraint. We consider here the node-disjointness variant as well as the edge-disjointness variant.

Definition 2.63 (Node-disjointness commodity (NC)). *A node-disjointness commodity q is a quadruple (s_q, t_q, k_q, h_q), where*

- *s_q, t_q are nodes of a given graph or network,*
- *$k_q \in \mathbb{N}_{\geq 1}$ denotes the required number of pairwise node-disjoint paths P_i $(1 \leq i \leq k_q)$ between s_q and t_q, i.e. $\kappa(s_q, t_q) \geq k_q$,*
- *$h_q \in \mathbb{N}_{\geq 1}$ denotes the hop limit, i.e. $l(P_i(s_q, t_q)) \leq h_q$, $\forall\ 1 \leq i \leq k_q$.*

Definition 2.64 (Hop Constrained Node Survivable Network Design Problem (HNSND)). *Consider a network $N = (G, c)$ and a set of node-disjointness commodities Q. We now want to find a minimum-cost subgraph $F \subseteq G$, such that all the constraints implied by the commodities Q are fulfilled.*

Definition 2.65 (Edge-disjointness commodity (EC)). *An edge-disjointness commodity q is a quadruple (s_q, t_q, k_q, h_q), where*

- *s_q, t_q are nodes of a given graph or network,*
- *$k_q \in \mathbb{N}_{\geq 1}$ denotes the required number of pairwise edge-disjoint paths P_i $(1 \leq i \leq k_q)$ between s_q and t_q, i.e. $\lambda(s_q, t_q) \geq k_q$,*
- *$h_q \in \mathbb{N}_{\geq 1}$ denotes the hop limit, i.e. $l(P_i(s_q, t_q)) \leq h_q$, $\forall\ 1 \leq i \leq k_q$.*

Definition 2.66 (Hop Constrained Edge Survivable Network Design Problem (HESND)). *Consider a network $N = (G, c)$ and a set of edge-disjointness commodities Q. We now want to find a minimum-cost subgraph $F \subseteq G$, such that all the constraints implied by the commodities Q are fulfilled.*

2.2.2 Version with individual hop limits

In some applications the hop limit must not be uniform. Instead, one of the paths between two given nodes may need to be faster than the others, we speak here from the primary path. Commodities are normally routed over this primary path. In case this path fails, the commodity has to be routed over an alternative path, i.e. the backup path. As commodities are not normally routed on the backup path and it is only used in case of failures, it must not be necessarily as fast as the primary path. Hence, the hop limits may be different for the individual paths. The version with individual hop limits is a variant of the basic version.

Definition 2.67 (Node-disjointness commodity with individual hop limits (NC-IH))**.** *A node-disjointness commodity with individual hop limits q is a quadruple $(s_q, t_q, k_q, \boldsymbol{h_q})$, where*

- s_q, t_q *are nodes of a given graph or network,*
- $k_q \in \mathbb{N}_{\geq 1}$ *denotes the required number of pairwise node-disjoint paths P_i $(1 \leq i \leq k_q)$ between s_q and t_q, i.e. $\kappa(s_q, t_q) \geq k_q$,*
- $\boldsymbol{h_q} \in \mathbb{N}_{\geq 1}^{k_q}$ *is a k_q-dimensional vector which denotes the individual hop limits, i.e. $l(P_i(s_q, t_q)) \leq (h_q)_i \ \forall\ 1 \leq i \leq k_q$.*

Definition 2.68 (Hop Constrained Node Survivable Network Design Problem with individual hop limits (HNSND-IH))**.** *Consider a network $N = (G, c)$ and a set of node-disjointness commodities with individual hop limits Q. We now want to find a minimum-cost subgraph $F \subseteq G$, such that all the constraints implied by the commodities Q are fulfilled.*

Definition 2.69 (Edge-disjointness commodity with individual hop limits (EC-IH))**.** *An edge-disjointness commodity with individual hop limits q is a quadruple $(s_q, t_q, k_q, \boldsymbol{h_q})$, where*

- s_q, t_q *are nodes of a given graph or network,*
- $k_q \in \mathbb{N}_{\geq 1}$ *denotes the required number of pairwise edge-disjoint paths P_i $(1 \leq i \leq k_q)$ between s_q and t_q, i.e. $\lambda(s_q, t_q) \geq k_q$,*
- $\boldsymbol{h_q} \in \mathbb{N}_{\geq 1}^{k_q}$ *is a k_q-dimensional vector which denotes the individual hop limits, i.e. $l(P_i(s_q, t_q)) \leq (h_q)_i \ \forall\ 1 \leq i \leq k_q$.*

Definition 2.70 (Hop Constrained Edge Survivable Network Design Problem with individual hop limits (HESND-IH))**.** *Consider a network $N = (G, c)$ and a set of edge-disjointness commodities with individual hop limits Q. We now want to find a minimum-cost subgraph $F \subseteq G$, such that all the constraints implied by the commodities Q are fulfilled.*

2.2.3 Prize collecting version

The term "prize collecting" was introduced by Balas [6]. In some cases it is not useful to fulfill all commodities, consider e.g. a commodity that is very expensive to build and maintain and brings no reasonable profit. Therefore we take a look at the prize collecting version as a variant of the basic version of the Hop Constrained

Survivable Network Design Problem, where every commodity additionally has a profit and therefore the sum of the costs and the profits not gained has to be minimal.

Definition 2.71 (Node-disjointness commodity with profit (NC-P)). *A node-disjointness commodity with profit q is a quintuple $(s_q, t_q, k_q, h_q, p_q)$, where*

- s_q, t_q *are nodes of a given graph or network,*
- $k_q \in \mathbb{N}_{\geq 1}$ *denotes the required number of pairwise node-disjoint paths P_i $(1 \leq i \leq k_q)$ between s_q and t_q, i.e. $\kappa(s_q, t_q) \geq k_q$,*
- $h_q \in \mathbb{N}_{\geq 1}$ *denotes the hop limit, i.e. $l(P_i(s_q, t_q)) \leq h_q \; \forall \; 1 \leq i \leq k_q$,*
- $p_q \in \mathbb{R}_{\geq 0}$ *denotes the profit gained from fulfilling this commodity.*

Definition 2.72 (Prize Collecting Hop Constrained Node Survivable Network Design Problem (HNSND-PC)). *Consider a network $N = (G, c)$ and a set of node-disjointness commodities with profit Q. We now want to find a subgraph $F = (V_F, E_F) \subseteq G$, satisfying a subset of the commodities $Q_F \subseteq Q$, such that the sum of all costs plus the profits not gained is minimal, i.e.*

$$min \sum_{e \in E_F} c_e + \sum_{q \notin Q_F} p_q$$

Definition 2.73 (Edge-disjointness commodity with profit (EC-P)). *An edge-disjointness commodity with profit q is a quintuple $(s_q, t_q, k_q, h_q, p_q)$, where*

- s_q, t_q *are nodes of a given graph or network,*
- $k_q \in \mathbb{N}_{\geq 1}$ *denotes the required number of pairwise edge-disjoint paths P_i $(1 \leq i \leq k_q)$ between s_q and t_q, i.e. $\lambda(s_q, t_q) \geq k_q$,*
- $h_q \in \mathbb{N}_{\geq 1}$ *denotes the hop limit, i.e. $l(P_i(s_q, t_q)) \leq h_q \; \forall \; 1 \leq i \leq k_q$,*
- $p_q \in \mathbb{R}_{\geq 0}$ *denotes the profit gained from fulfilling this commodity.*

Definition 2.74 (Prize Collecting Hop Constrained Edge Survivable Network Design Problem (HESND-PC)). *Consider a network $N = (G, c)$ and a set of edge-disjointness commodities with profit Q. We now want to find a subgraph $F = (V_F, E_F) \subseteq G$, satisfying a subset of the commodities $Q_F \subseteq Q$, such that the sum of all costs plus the profits not gained is minimal, i.e.*

$$min \sum_{e \in E_F} c_e + \sum_{q \notin Q_F} p_q$$

2.2.4 Further problem variants

It would also be possible to look at a prize collecting variant with individual hop limits or a modified prize collecting variant, where the profit is not lost en bloc, if a certain commodity is not fulfilled. Consider e.g. a commodity which requires three pairwise disjoint paths, restricted to certain hop limits. If we are now able to maintain two pairwise disjoint paths or a path which is a little longer than the hop limit, the profit should not be dropped as a whole but reduced to an amount which is appropriate for this misperformance.

Unfortunately, such considerations go far beyond the scope of this master's thesis.

2.3 Example network

Consider the following network with two node-disjointness commodities (s_1, t_1, k_1, h_1) and (s_2, t_2, k_2, h_2), as can be seen in Figure 2.1. Edge costs c_e are omitted for better readability.

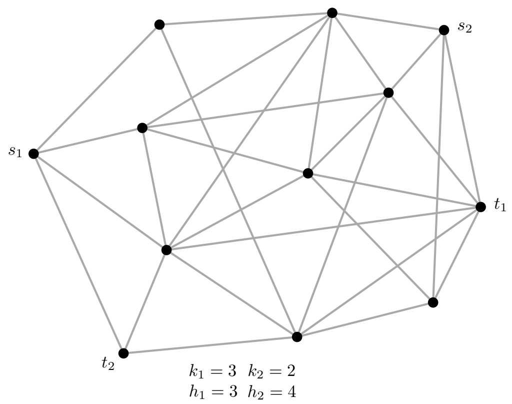


Figure 2.1: Example Network

Partial solutions, i.e. solutions for one of the two commodities can be seen in Figures 2.2(a) and 2.2(b). The combination of the two single solutions can be seen in Figure 2.2(c). A better solution to this instance is depicted in Figure 2.2(d).

As can be seen by comparison of figure 2.2(c) with figure 2.2(d), an optimal solution can look quite different from the combination of all single solutions. This is a result from the fact, that using an edge for more than one commodity yields a better solution because we have to "pay" the edge cost only once.

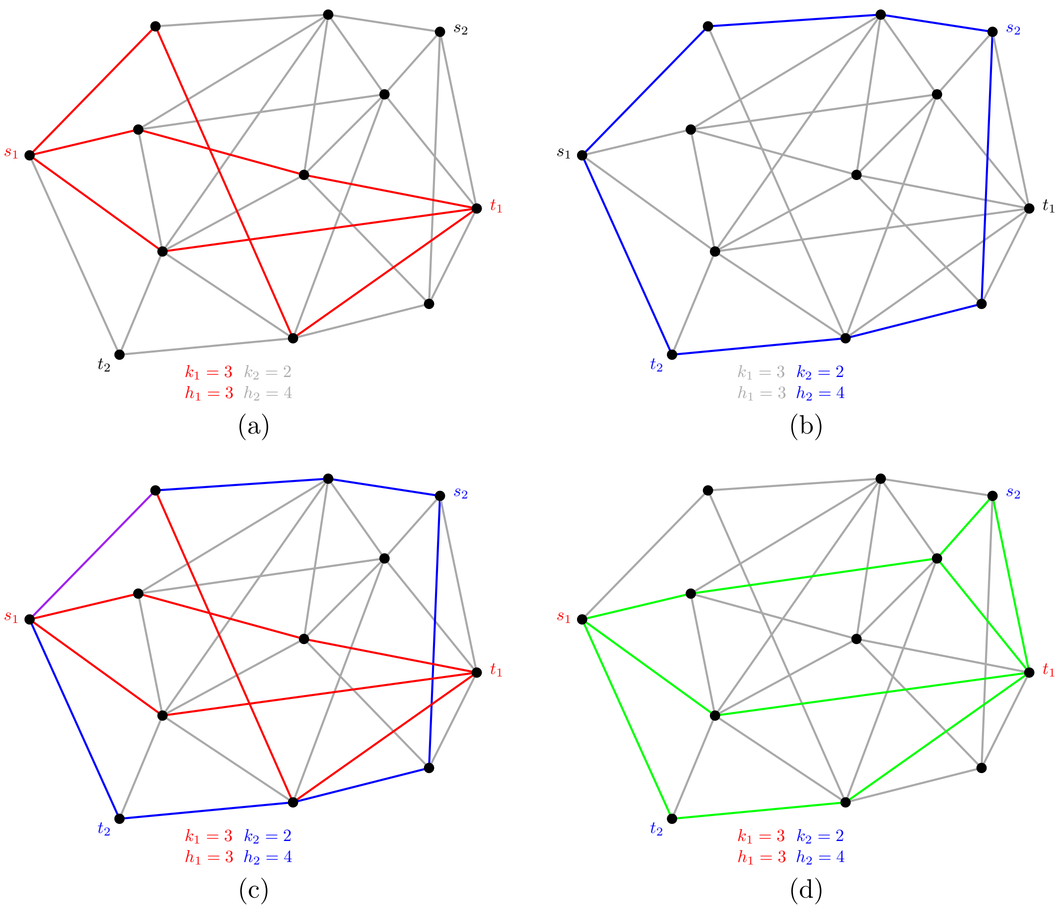


Figure 2.2: Subgraphs satisfying the requirements.

2.4 Related work

This section gives an overview on the previous work dealing with the Hop Constrained Survivable Network Design Problem, Survivable Network Design and related Hop Constrained Problems. We first review the exact approaches, i.e. algorithms which find provable optimal solutions. As this thesis is not dealing with exact mathematical methods, we confine ourselves here to a short review. Subsequently we look at heuristic approaches, as well as metaheuristic approaches dealing with specialized problems, subproblems and further related problems. We are not aware of any works advancing the Hop Constrained Survivable Network Design Problem with a metaheuristic approach. It must be said in advance, that most of the approaches, in fact all of the exact approaches, deal with uniform limits only, i.e the demanded number of disjoint paths and the hop limit are the same for each commodity.

2.4.1 Exact methods

2.4.1.1 Survivable network design

A good survey over work done on survivable network design is given by Kerivin and Mahjoub in [51], another one can be found in [75]. There are also different approaches in survivable network design, e.g. physical survivability or logical survivability, a very good classification is given in [75, 76].

Formulations for network design problems with connectivity requirements (as a superclass to survivable network design) are presented in [58]. Soni and Pirkul [76] provide an integer programming formulation for the Survivable Network Design Problem for either node disjointness or edge disjointness combined with a cut generation approach. Connectivity splitting models regarding survivable network design based on a mixed integer programming formulation are given in [5]. A dual-ascent algorithm for survivable network design with connectivity requirements is presented in [69]. Agarwal [1] solves the Survivable Network Design Problem with the help of a linear program by a heuristic Lagrangean relaxation technique and a partial branch-and-bound approach.

In [56], Leitner and Raidl present a Lagrangean decomposition approach for solving the last mile problem with redundancy requirements. Borne et al. [13] give an integer programming formulation for the Multilayer Survivable Network Design Problem and discuss the associated polytope as well as some facet defining inequalities, separation algorithms for these inequalities and a branch-and-cut algorithm. Rosenberg [72] discusses survivability issues in rectilinear grid communications network design in context with alternate routing in case of errors and upper bounds for the additional arc capacity requirements in case of failure. Walkowiak and Przewoźniczek [85] present a mixed integer programming formulation regarding survivable P2P multicasting. A mathematical formulation and a Lagrangean-based algorithm for the diverse routing problem in sparse backbone fiber optic networks can be found in [61].

2.4.1.2 Hop constraints

In [25], Dahl and Gouveia present valid inequalities for the directed hop-constrained shortest path problem and give complete characterizations of the linear polytopes in case the hop limit is less or equal to 3 as well as facet defining inequalities in case the hop limit is greater than 3. Pirkul and Soni [66] discuss a linear programming relaxation approach for the hop constrained network design problem and provide formulations including a dummy flow to ensure the hop constraint. In [73] a mathematical model for the capacitated hop-constrained per-packet wireless mesh network design problem is presented. In [59] a primal-dual approximation algorithm is presented which solves the Max Flow and Min Cut problems with bounded-length paths.

Most of the work regarding hop constraints, has been done for the hop constrained minimum spanning tree problem. In [40], Gouveia et al. showed that the hop constrained minimum spanning tree problem is equivalent to a Steiner tree problem in an appropriate layered graph and they provided Steiner directed cut models. Formulations based on tightened Miller-Tucker-Zemlin constraints are presented in [4], but the authors state by themselves that their formulation does not dominate flow-based and hop-indexed formulations. Much work in the field of exact mathematical methods on the hop constrained minimum spanning tree problem (especially Lagrangean relaxations) has been done by Gouveia in [37, 39]. In [23], Dahl addresses the 2-hop spanning tree problem from a polyhedral point of view. An integer programming formulation for the 2-path network problem, which demands for each given pair of nodes a path with length at most 2, is presented in [26] and the associated polytopes as well as cutting planes are studied.

2.4.1.3 Hop constrained survivable network design

In [24], the research is limited to a hop limit of 2 for the edge-disjointness case and the associated polytope is well characterized. Gouveia et al. [38] present an integer programming formulation for the Hop Constrained Node Survivable Network Design Problem in context of multi-protocol label switching over wavelength division multiplexing network and investigate the cases where the number of node disjoint paths is at most 4. In [74], Soni gives an integer programming formulation and an efficient solution procedure based on linear programming relaxation for the Hop Constrained Network Design Problem with Partial Survivability, where partial survivability means two node disjoint paths for each commodity. In [14], a model is presented for the single edge-disjointness commodity case using a layered graph transformation. Huygens et al. [46, 47] give an integer programming formulation restricted to a hop limit of 2 or 3 for the edge-disjoint case. The first formulation for the Hop Constrained Edge Survivable Network Design Problem which allows arbitrary (but nevertheless uniform) values for both the hop constraint and survivability constraint is provided by Botton et al. in [15]. They use a Benders Decomposition and present a branch-and-cut approach.

Work regarding the edge-disjoint hop constrained paths problem can be found in [7] with restriction to a hop limit of 3 and a computational study for the case that the hop limit is greater than 3 is given in [8]. Another related problem, the two connected networks with rings of bounded cardinality, is discussed in [34] and lower bounds on the number of edges in a feasible solution are presented as well as a new class of facet defining inequalities for this problem. In [33], work has been done on the two-edge connected subgraphs with bounded rings, where an integer programming formulation including cycle inequalities is given and the associated polytope is well studied.

2.4.1.4 Finding disjoint paths

An algorithm for finding the K (provably optimal) shortest node-disjoint paths is presented by Suurballe in [81]. An algorithm for finding the K (provably optimal) shortest edge-disjoint paths, which is much faster than its node-disjoint equivalent, is presented by Suurballe and Tarjan in [80]. Algorithms for solving the maximum edge (node) disjoint path problem with length constraints can be found in [49] and - dealing only with node-disjointness - in [71]. Xu et al. [87] present an algorithm for solving the Min-Min problem, where two disjoint paths are required and one needs to minimize the length of the shorter path. A more enhanced problem, where every edge is assigned more than one cost value and one yields to minimize the cost of disjoint paths in all cost functions, is discussed in [57] and solution heuristics are proposed. Algorithms for finding the constrained K shortest paths are presented in [88]. An algorithm for computing the local node connectivity between a pair of nodes is presented in [77].

2.4.2 Heuristic approaches

We will now briefly discuss the metaheuristic and heuristic approaches. We will go in more detail in the following chapters, in case a heuristic approach may be fruitful for our solution techniques.

2.4.2.1 Metaheuristics

Despite its practical interest, we are not aware of previous work dealing with metaheuristics as solution procedure for Hop Constrained Survivable Network Design. For some related problems metaheuristic approaches have been proposed.

In [56], a generalization of the (prize collecting) Steiner tree problem with redundancy requirements is considered. The authors design a three-phase construction heuristic called Minimum Spanning Tree Augmentation Heuristic and several neighborhoods for the purposes of a variable neighborhood descend (VND), which they use in a variable neighborhood search (VNS) framework and in a greedy randomized adaptive search procedure (GRASP) approach. In [84], a simple restricted cheapest insertion heuristic as well as a dynamic Tabu Search approach is proposed to produce initial feasible solutions for the hop constrained Steiner tree problem.

An evolutionary algorithm for survivable P2P multicasting called SuTec (Survivable Tree Constructor) is developed in [85]. For the design of backbone wireless mesh networks with survivability constraints a genetic algorithm as well as an enhanced Dijkstra's algorithm is presented in [45]. These approaches are employed to search for a minimum cost network with constraints such as survivability, link capacity, degree limitation and maximum tolerable delay. A genetic algorithm for yet another related problem, network design with throughput demand, hop-limit and path diversity constraints, is given in [43], where also much work is done on the encoding of hop-constrained disjoint paths. An Ant Colony Optimization for the Maximum Edge-Disjoint Paths Problem can be found in [9].

2.4.2.2 Heuristics for related problems

Gouveia [37] presents a heuristic for the hop constrained minimal spanning tree problem, which transforms a spanning tree into a hop constrained spanning tree. A Divide-and-Conquer algorithm, called h-party algorithm, for the multidimensional hop constrained minimum spanning tree problem is proposed in [22]. An algorithm for solving the hop constrained sub-path problem is given in [19]. This algorithm is able to compute so called primary subpaths and backup subpaths with hop constraints.

In [21], many heuristics (construction heuristics as well as improvement heuristics) are discussed for solving the minimum cost survivable network design problem. Algorithms for solving the survivable network design problem, when only two disjoint paths are required, are presented in [63]. The authors are presenting construction heuristics as well as improvement heuristcs to be used in a local search approach. Heuristics for survivable network design based on work for the TSP are proposed in [78]. In [86], a heuristic algorithm for the design of centralized networks with reliability and availability constraints is presented.

An approximation algorithm for solving the biconnectivity augmentation problem is given in [35]. Another approximation algorithm for the previously mentioned 2-path network problem is presented in [26]. An approximation algorithm for the bounded length edge-disjoint path problem is proposed in [41].

2.5 Complexity

Finding the maximum possible number K of disjoint paths is possible in polynomial time, regardless of whether edge-disjointness [80] or node-disjointness [81]. Hence, solving one single commodity without hop limits is in P. Solving even a single commodity with a hop limit greater than 4 is NP-complete [10, 11, 14, 49]. It has also been shown that in case the hop limit equals 4 the edge-disjointness variants are more complex than in the node-disjoint case [12, 49].

Survivable network design is NP-hard [21, 53, 79], regardless of whether edge-disjointness or node-disjointness. It is even strongly NP-hard [51], which means that there even does not exist a pseudopolynomial algorithm. With certain restrictions (which we will not consider here), such as uniform costs, there are some polynomially solvable cases [79]. As the Survivable Network Design Problem is a special case of the Hop Constrained Survivable Network Design Problem, the latter must at least be NP-hard. If we can develop an algorithm which checks, whether a given solution is a feasible solution, and this check can be done in polynomial time, we have proven NP-membership and, hence, that the Hop Constrained Survivable Network Design Problem is not only NP-hard, but even NP-complete [36, 65]. By representing the solution as a set of paths PA and building the subgraph $F = \bigcup_{p \in PA} p$, it is clearly possible in polynomial time to check, if in the set of paths PA there are at least k_q disjoint paths between every (s_q, t_q)-"pair" and if these paths fulfill the length requirements. Hence, NP-membership is shown and therefore the Hop Constrained Survivable Network Design Problem is NP-complete. The NP-completeness not only holds for the basic version, but as well for the version with individual hop constraints and the prize collecting version, as the latter two have the basic version as a special case.

Chapter 3

Preprocessing and solving subproblems

In this chapter we present algorithms for preprocessing the network, i.e. determining the structural information of a graph like components, blocks and cutpoints. Moreover, algorithms are developed for transforming graphs – so we can solve edge-disjointness requirements with an algorithm for node-disjointness and vice versa – and testing feasibility of a solution, given as a subgraph or a set of paths. Furthermore algorithms are presented, which heuristically solve the single commodity case.

The algorithms we develop are for the HNSND. We will in the following outline how the algorithms have to be changed for the HESND if changes are needed for the edge-disjointness case, without going into great detail.

3.1 Preprocessing

In this section we first give algorithms to divide a graph into components and blocks, as well as to determine cutpoints and bridges. Decomposition helps us in further solution approaches to restrict the search space. We will then present algorithms which transform a given graph, so that an algorithm for node-disjointness can be used in case edge-disjointness is required and vice versa.

3.1.1 Components

By dividing the graph into its components we do not intend to restrict the search space. No algorithm would encounter a node from another component anyway, simply by the fact that it is not reachable. But dividing the graph into components helps to check quickly if any feasible solution exists. Let $comp(v)$ be the number of the component the node v is in.

Proposition 3.1. *If $comp(s_q) \neq comp(t_q)$ for any $q \in Q$, then there can not be any feasible solution, as t_q is not reachable from s_q.*

So, dividing the graph into components now helps to check quickly if any feasible solution exists.

Algorithm 3.1, which we use for determining the components of a graph, is a variant from Depth-First-Search (DFS), DFS is explained e.g. in [17].

Algorithm 3.1 DetermineComponents(G)

Input: A graph $G = (V, E)$
Output: The number of components and the array $comp(v)$

1: $i := 0$
2: **for all** $v \in V$ **do**
3:     $comp(v) := \infty$
4: **end for**
5: **while** $\exists v \in V$ with $comp(v) = \infty$ **do**
6:     $i := i + 1$
7:     $DCSearch(v, i)$
8: **end while**

In line 7 of Algorithm 3.1 the recursive subroutine $DCSearch(v, i)$ is called, which is described in Algorithm 3.2.

Theorem 3.2. *Algorithm 3.1 is correct and its runtime is $O(|V| + |E|)$.*

Proof. It follows from the DFS that Algorithm 3.1 eventually reaches every node. Via the recursion of Algorithm 3.2 every node reachable from v as given in line 7 of Algorithm 3.1 is examined. Hence, all the nodes reachable from this v have the same component value. As they are reachable from v they are in the same component. When there is still some other node (not reachable from v), it and all other nodes reachable from it get another component number and so on. So in the end all nodes x in one component have the same component value $comp(x)$.

Moreover, i is the number assigned to the last node during the search and, hence, denotes the number of components.

As this algorithm is a variant of DFS where the counter i is not incremented with every visited node, but with every visited component, the runtime is the same as for the DFS, i.e. $O(|V| + |E|)$ [17]. □

Algorithm 3.2 DCSearch(v, i)

Input: A node v and a natural number i

```
comp(v) := i
while ∃w ∈ N(v) with comp(v) = ∞ do
    DCSearch(w, i)
end while
```

3.1.2 Blocks, cutpoints and bridges

As said before, dividing a graph into its blocks aims to restrict the search space. Dividing a graph into blocks also helps us in deciding quickly, if a feasible solution is possible, see Lemma 3.3.

Lemma 3.3. *If the starting node s_q and the end node t_q of a commodity lie in the same component, but in two different blocks, w.l.o.g. $s_q \in B_1$ and $t_q \in B_2$, and $k_q > 1$, then there are no k_q disjoint paths.*

Proof. Assume, there are $k_q > 1$ disjoint paths between $s_q \in B_1$ and $t_q \in B_2$. By Proposition 2.37, the block-cutpoint-graph of the component is a tree. Hence, there is exactly one unique path from B_1 to B_2, contradicting the assumption that there are $k_q > 1$ disjoint paths between s_q and t_q. □

Deciding quickly in advance if there can be a feasible solution is helpful, but, in consequence of Theorem 3.4, determining the blocks of a graph makes it possible to restrict the search space.

Theorem 3.4. *If the starting node s_q and the end node t_q of a commodity lie in the same block B, then only this block B has to be searched.*

Proof. Assume, there is a path from s_q to t_q containing an edge $e \notin B$ and therefore also a node $v \notin B$. Hence, in the block-cutpoint-graph, B lies on a cycle. But this is a contradiction to Proposition 2.37. Therefore no path from s_q to t_q contains an edge $e \notin B$ and so it suffices to search only B. □

Now let us take a look on our algorithm for determining the blocks of a graph. Algorithm 3.3 for determining the biconnected components of a graph, i.e. blocks, was first proposed by Hopcroft and Tarjan [44] as a variant of DFS. We adapted this algorithm slightly. Let $bl(v)$ be a set of numbers which denote the blocks a node is in. It is possible that a node is part of more than one block. This is the case, when it is a cutpoint. Hence, by determining the blocks of a graph and numbering the nodes with "block numbers" we can also find cutpoints. If we store the number of vertices in a given block B, then we could also determine the bridges, i.e. blocks with exactly two nodes and, hence, one edge. Furthermore, let $cp(v) = true$ if v is a cutpoint and $false$ otherwise. *edgestack* denotes a stack with the following operations: *stack.top*() returns the element on the top of the stack, *stack.push*(E) puts an element E at the top of the stack and *stack.pop*() deletes the element on the top of the stack from the stack. Further information on this algorithm can be found in [44] and [82].

Algorithm 3.3 DetermineBlocks(G)

Input: A graph $G = (V, E)$
Output: The number of blocks, the array $bl(v)$ and the array $cp(v)$

$i := 0$
$bn := 0$
for all $v \in V$ **do**
    $bl(v) := \emptyset$
    $cp(v) := false$
    $t(v) := \infty$
end for
while $\exists v \in V$ with $t(v) = \infty$ **do**
    $DBSearch(v, 0, i)$
end while
for all $v \in V$ **do**
    if $|bl(v)| > 1$ **then**
        $cp(v) := true$
    end if
end for

Algorithm 3.4 is a recursive subroutine used by Algorithm 3.3. It is closely related to the DFS. Briefly, if the condition in line 9 is fulfilled, a cutpoint has been found, namely v. We do not set $cp(v) = true$ in this early phase because on the one hand the root of the DFS-tree needs special treatment and on the other hand we can set it at the end in $O(|V|)$ for all nodes. In lines 10 to 18 the nodes of the found block are labeled. More information on how this algorithm works in detail and the theoretical background on which this algorithm is based can be found in [44] and [82].

Algorithm 3.4 DBSearch(v, u, i)

Input: A node v, the predecessor node u and a natural number i

```
i := i + 1
t(v) := i
lowpt(v) := t(v)
for all w ∈ N(v) do
   if t(w) = ∞ then
      edgestack.push({v, w})
      DBSearch(w, v, i)
      lowpt(v) := min{lowpt(v), lowpt(w)}
      if lowpt(w) ≥ t(v) then
         bn := bn + 1
         while e := {u_1, u_2} := edgestack.top() has t(u_1) ≥ t(w) do
            bl(u_1) := bl(u_1) ∪ {bn}
            bl(u_2) := bl(u_2) ∪ {bn}
            edgestack.pop()
         end while
         bl(w) := bl(w) ∪ {bn}
         bl(v) := bl(v) ∪ {bn}
         edgestack.pop()
      end if
   else
      if t(w) < t(v) and w ≠ u then
         edgestack.push({v, w})
         lowpt(v) := min{lowpt(v), t(w)}
      end if
   end if
end for
```

Theorem 3.5. *Algorithm 3.3 is correct and its runtime is* $O(|V| + |E|)$.

Proof. For the correct labelling of the blocks and cutpoints, as well as the runtime see [44] and [82]. That in the end, *bn* stores the number of blocks is easy to see, as it is the value the last encountered block is labeled with in the algorithm. □

3.1.3 Graph transformation

Given a graph G, we are able to solve edge-disjointness commodities on a transformed graph G' with the help of an algorithm for node-disjointness and get a solution for edge-disjointness via back-transforming the paths, and vice versa. We will now present these two transformation procedures.

Algorithm 3.5 TransformForUsingNodeDisjoint(G)

Input: A graph $G = (V, E)$
Output: The transformed graph $G' = (V', E')$

$V' = \emptyset$
$E' = \emptyset$
for all $v \in V$ **do**
    $nr(v) := 0$
    for $i := 1$ **to** $d(v)$ **do**
        $V' := V' \cup v_i$
        for $j := 1$ **to** $i - 1$ **do**
            $E' := E' \cup \{v_j, v_i\}$
        end for
    end for
end for
for all $e = \{u, v\} \in E$ **do**
    $nr(u) := nr(u) + 1$
    $nr(v) := nr(v) + 1$
    $E' := E' \cup \{u_{nr(u)}, v_{nr(v)}\}$
end for

Suppose, we want to solve edge-disjointness commodities on a graph G and we have developed an algorithm which can solve the node-disjointness case. We can now use the algorithm for node disjointness on a transformed graph G' to solve the edge-disjointness commodities on G. This graph transformation procedure is described in Algorithm 3.5 and depicted in Figure 3.1.

Algorithm 3.5 works as follows. Every node v is converted into a complete graph with $d(v)$ nodes, where the nodes are labeled $v_1, v_2, ..., v_{d(v)}$ and every edge $\{v, x\}$ is now incident to exactly one of the nodes of this $K_{d(v)}$. Every edge of this $K_{d(v)}$ gets edge cost 0, whereas the edge costs of the original edges remain unchanged. Furthermore, we have to adapt the commodities by setting $h_{q'} = 2 \cdot h_q - 1$.

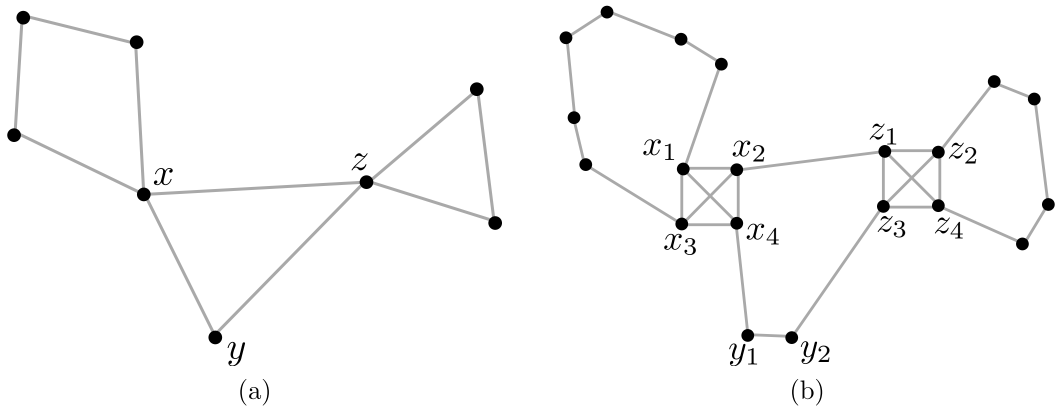


Figure 3.1: Example for transforming graph G (a) into graph G' (b).

As every node can have at most $|V| - 1$ neighbors, in the worst case Algorithm 3.5 has runtime $O(|V|^2 + |E|)$. The node-disjoint paths in G' can then be back-transformed into edge-disjoint paths on G in linear time.

Algorithm 3.6 TransformForUsingEdgeDisjoint(G)

Input: A graph $G = (V, E)$
Output: The transformed directed graph $D' = (V', A')$

```
V' = ∅
A' = ∅
for all v ∈ V do
    V' := V' ∪ v_1
    V' := V' ∪ v_2
    A' := A' ∪ (v_1, v_2)
end for
for all e = {u, v} ∈ E do
    A' := A' ∪ (u_2, v_1)
end for
```

Now let us consider the opposite case. Suppose, we have developed an algorithm for edge-disjointness, but we are interested in node-disjointness. Also in this case we are presenting a transformation algorithm which allows us to use the algorithm for edge-disjointness on a transformed (directed) graph D' which yields - after back-transforming - node-disjoint paths on G.

Algorithm 3.6 doubles all nodes and connects them via directed arcs, as depicted in Figure 3.2. The new arcs (v_1, v_2) get cost 0, whereas the cost of the orig-

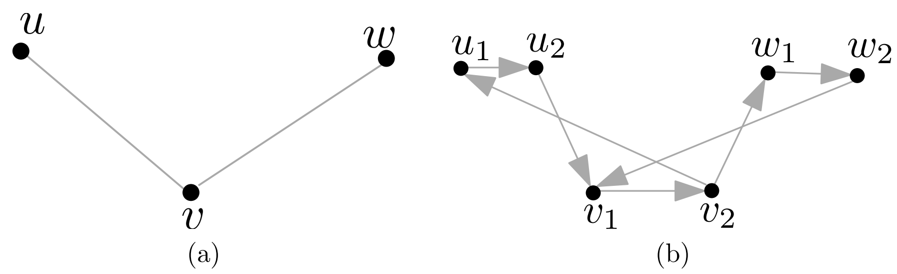


Figure 3.2: Example for transforming graph G (a) into graph D' (b).

inal edges remains unchanged. When running an algorithm for edge-disjointness on the transformed graph D', we have to adapt the commodities as follows: For $s_q = v$, $s_{q'} = v_2$ and for $t_q = v$, $t_{q'} = v_1$ and $h_{q'} = 2 \cdot h_q - 1$. Algorithm 3.6 has runtime $O(|V| + |E|)$.

So we know now that solving either the node-disjointness variant or the edge-disjointness variant suffices, as we can use one method for the other problem on a transformed graph and after back-transforming we get the required paths. But as these transformation algorithms blow up the graph, in the case of algorithm 3.5 even quadratically, we will in the following present solution algorithms for the node-disjoint case as well as for the edge-disjoint case.

3.2 Testing feasibility on a graph

As already mentioned earlier, finding disjoint paths with hoplimit is *NP*-complete for any hoplimit greater than 4. This has been shown via a reduction from 3-SAT [10, 49]. The latter problem is known to be *NP*-complete. From this reduction follows that checking, if in a graph G, for any given K, there are at least K disjoint paths with a hoplimit greater than 4, is already *NP*-complete. We will in the following nevertheless present an algorithm for this problem.

We like to state in advance that there is no feasibility test for the HNSND-PC and the HESND-PC, as in the price collecting variant every solution is a feasible one, even the empty solution. Given the solution as a subgraph, we present in the following an algorithm, that tests feasibility of a solution for the HNSND. This algorithm can be used for the HESND by transforming the graph with Algorithm 3.5. But as already stated in advance we outline the changes for the HESND. The algorithm can also be used for the HNSND-IH and the HESND-IH by adapting the algorithm. As adapting it is no difficult task, we will spare the details here.

3.2.1 Quick feasibility check

At first, we will present a quick check, if a feasible solution is possible, based on Proposition 3.1 and Lemma 3.3. This quick check works for the HNSND and the HNSND-IH, for HESND and HESND-IH the block-check has to be omitted.

Algorithm 3.7 requires that the arrays $comp(v)$ and $bl(v)$ have been set after executing Algorithm 3.1 and Algorithm 3.3 and has runtime $O(|Q|)$. An algorithm that quick checks only one commodity is presented in Algorithm 3.8. The latter algorithm has constant runtime.

Algorithm 3.7 QuickFeasibilityCheck(G, Q)

Input: A graph G and a set of commodities Q

Output: $true$, if the quick check was successful, $false$ otherwise

```
for all q ∈ Q do
    if (k_q = 1 ∧ comp(s_q) ≠ comp(t_q)) ∨ (k_q > 1 ∧ bl(s_q) ∩ bl(t_q) = ∅) then
        return false
    end if
end for
return true
```

Algorithm 3.8 QuickFeasibilityCheck(G, q)

Input: A graph G and a commodity q

Output: $true$, if the quick check was successful, $false$ otherwise

```
if (k_q = 1 ∧ comp(s_q) ≠ comp(t_q)) ∨ (k_q > 1 ∧ bl(s_q) ∩ bl(t_q) = ∅) then
    return false
end if
return true
```

3.2.2 Advanced feasibility check

The next algorithm is a more advanced feasibility check, as it gives in general a quite good upper bound for the maximum number of disjoint paths with a given hop limit. Therefore, if k_q is greater than this upper bound, then no feasible solution is possible. In order to understand this algorithm, we have to deal with some graph theory first.

Definition 3.6 (H-restricted separating vertex set)**.** *Given two non adjacent nodes x and y and a hoplimit H, we call a set $S_H \subset V$ a H-restricted separating* *vertex set for x and y, if every $P(x, y)$ with length at most H has at least one node in S_H.*

Definition 3.7 (H-bounded node disjoint paths)**.** *The maximum number of pairwise node disjoint paths between two nodes x and y, i.e. paths that share no node except the start node x and the end node y, with length at most H is denoted by $\rho_H(x, y)$.*

Corollary 3.8. *Given a H-restricted separating vertex set S_H for two nodes x and y, $\rho_H(x, y) \leq |S_H|$.*

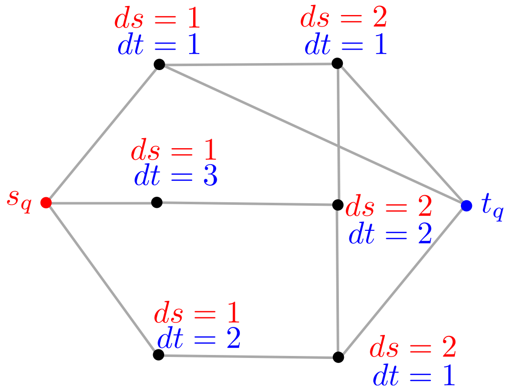
Proof. Suppose, $\rho_H(x, y) > |S_H|$. Then there exists some path from x to y, where no node of this path is in S_H and the path is node disjoint to all other paths, which have nodes in S_H. But then S_H would not be a H-restricted separating vertex set for x and y. Hence, $\rho_H(x, y) \leq |S_H|$. □

Proposition 3.9. *If s_q and t_q are adjacent, we can make them non adjacent without changing the solution or the solution value, given $h_q \geq 2$. For this end, we insert an intermediate node v_{int} and and change the edge $e = \{s_q, t_q\}$ into $e = \{s_q, v_{\text{int}}\}$, whereas $c(e)$ remains unchanged. Furthermore, we insert a new edge $f = \{v_{\text{int}}, t_q\}$ and let $c(f) = 0$.*

Due to Proposition 3.9 we always can make sure that s_q and t_q are non adjacent and hence, apply Corollary 3.8.

Algorithm 3.9 now works as follows. First, a depth-restricted Breadth First Search (BFS) starting from s_q is conducted. BFS is explained e.g. in [17]. The nodes reached by this search are numbered according to their level in the BFS tree, i.e. this number gives the distance from s_q, which equals the minimum length of a path from s_q to this node. Let this number be denoted as $ds(v)$, e.g. $ds(v) = 4$ means, that v is reachable from s_q via a path with 4 edges, but not via a path with less edges. According to Theorem 3.4 only the nodes in the same block as s_q and t_q have to be searched. We do not have to handle the case $k_q = 1$ explicitly, as this is obviously possible, if Algorithm 3.7 returned *true*. Then another depth-restricted BFS from t_q is conducted and the nodes are again numbered according to their level in the BFS tree. Let this number be denoted as $dt(v)$.

Next, a set S is constructed, which contains all the nodes $v \in V$, where $ds(v) + dt(v) \leq h_q$. In other words, this set contains only nodes that in principle can be on a path from s_q to t_q with length at most h_q. Then the two BFS are conducted again on a new graph $G' = G - \overline{S}, \overline{S} = \{v \mid v \neq S\}$, i.e. the nodes are again numbered during the search and only the nodes are kept, where $ds(v) + dt(v) \leq h_q$. This is



(a)

$\lvert S_s(1)\rvert = 3$	$buf_s(1) = 0$
$\lvert S_s(2)\rvert = 3$	$buf_s(2) = 1$
$\lvert S_s(3)\rvert = 0$	$buf_s(3) = 3$
$\lvert S_t(1)\rvert = 3$	$buf_t(1) = 0$
$\lvert S_t(2)\rvert = 2$	$buf_t(2) = 1$
$\lvert S_t(3)\rvert = 1$	$buf_t(3) = 2$

(b)

Figure 3.3: Example graph depicted in (a), the values can be seen in (b).

done, until $\overline{S} = \emptyset$, i.e. all nodes were kept in the last iteration. Furthermore, let $S_s(l) = \{v \in S \mid ds(v) = l\}$ be the set of nodes, which are in level l in the BFS tree starting at s_q and $S_t(l) = \{v \in S \mid dt(v) = l\}$ be the set of nodes, which are in level l in the BFS tree starting at t_q. E.g. $S_t(3)$ is the set of all nodes which can be reached from t_q via 3 edges, but not via a path with less edges.

Furthermore, let $buf_s(l)$ denote an upper bound for the cardinality of a set of nodes in one level of the BFS tree starting at s_q where $ds(v) + dt(v) \leq l$, i.e. $buf_s(l) = \max_{lvl} |\{v \in S \mid ds(v) = lvl \wedge ds(v) + dt(v) \leq l\}| + buf_s(l-1)$. $buf_t(l)$ is defined as $buf_t(l) = \max_{lvl} |\{v \in S \mid dt(v) = lvl \wedge ds(v) + dt(v) \leq l\}| + buf_t(l-1)$, correspondingly. In addition, obviously $buf_s(1) = 0$ and $buf_t(1) = 0$, as $ds(v) \geq 1$ and $dt(v) \geq 1$ always holds and therefore, $ds(v) + dt(v) \leq 1$ is never true.

Algorithm 3.9 returns $false$ if the advanced check failed and $true$ otherwise. The theoretical background of the advanced check, as well as a formal proof of correctness, is given in the following. Figure 3.3 shows an example graph and the corresponding values, which have just been outlined.

Algorithm 3.9 AdvancedFeasibilityCheck(G, q)

Input: A graph G and a commodity q

Output: $true$, if the advanced check was successful, $false$ otherwise

```
G' := ComputeGraphInducedByS(G, q)
if (k_q > min_l(|S_s(l)| + buf_s(l)) ∨ (k_q > min_l(|S_t(l)| + buf_t(l)) then
    return false
end if
return true
```

Algorithm 3.9 and Algorithm 3.10 work as described before. The labeling of the nodes according to their level in the BFS trees, invoked in line 5 of Algorithm 3.10, is a variant of BFS and described in Algorithm 3.11.

Algorithm 3.11 and Algorithm 3.12 work as described before. Starting from s the nodes are labeled according to their level in the BFS tree starting from s in the array $ds(v)$ and they are labeled according to their level in the BFS tree starting from t in the array $dt(v)$. This is done until depth $h-1$ in both cases.

Algorithm 3.10 ComputeGraphInducedByS(G, q)

Input: A graph $G = (V, E)$ and a commodity q
Output: A set S and the graph induced by S

1: $G' :=$ Block that contains s_q
2: **repeat**
3:     $S := \emptyset$
4:     $\overline{S} := \emptyset$
5:     $LabelNodes(G', s_q, t_q, h_q)$
6:     **for all** $v \in V'$ with $bl(v) \cap bl(s_q) \neq \emptyset$ **do**
7:         **if** $ds(v) + dt(v) \leq h_q$ **then**
8:             $S := S \cup \{v\}$
9:         **else**
10:             $\overline{S} := \overline{S} \cup \{v\}$
11:         **end if**
12:     **end for**
13:     $G' := G' - \overline{S}$
14: **until** $\overline{S} = \emptyset$
15: **return** G'

Algorithm 3.11 LabelNodes(G, s, t, h)

Input: A graph G, two nodes s and t and a depth limit h
Output: The arrays $ds(v)$ and $dt(v)$

for all $v \in V$ with $bl(v) \cap bl(s) \neq \emptyset$ **do**
    $ds(v) = \infty$
    $dt(v) = \infty$
end for
$LNSearch(s, t, ds, h)$
$LNSearch(t, s, dt, h)$

Algorithm 3.12 LNSearch(u_1, u_2, arr, h)

Input: Starting node u_1, end node u_2, an array arr and a depth limit h
Output: The correct labeling in arr starting from u

$W := \{u_1\}$
$arr(u_1) := 0$
$i := 1$
while $W \neq \emptyset$ and $i \neq h$ **do**
  Take first node $v \in W$
  $W := W \setminus \{v\}$
  if $arr(v) = i$ **then**
    $i := i + 1$
  end if
  while $\exists w \in N(v)$ with $w \neq u_2 \wedge bl(w) \cap bl(u_1) \neq \emptyset \wedge arr(w) = \infty$ **do**
    $arr(w) = i$
    Add w to the end of W
  end while
end while

Lemma 3.10. *After executing Algorithm 3.9, all nodes, that are part of any path between s_q and t_q with length at most h_q, are contained in S.*

Proof. Assume, there is a node $v \in V$, which is not in S, but is part of a path between s_q and t_q with length at most h_q. Then, if the distance from v to s_q is $p = ds(v)$, it follows that the distance from v to t_q can be at most $h_q - p = dt(v)$, otherwise v could not be on a path from s_q to t_q with length at most h_q. But then $ds(v) + dt(v) \leq h_q$ and hence, this node v must be contained in S, contradicting the assumption, that $v \notin S$. Therefore, S contains all nodes, that are part of any path between s_q and t_q with length at most h_q. □

Corollary 3.11. *S, as constructed by Algorithm 3.9, is a h_q-restricted separating vertex set for s_q and t_q.*

Proof. As by Lemma 3.10, S contains all nodes, that are part of any path between s_q and t_q with length at most h_q, it clearly is a h_q-restricted separating vertex set for s_q and t_q. □

Hence, we know now from Corollary 3.11, that, due to Corollary 3.8, $|S|$ is an upper bound for $\rho_{h_q}(s_q, t_q)$.

As every path between s_q and t_q must contain one node which is adjacent to s_q, it follows that also the first level of the BFS tree starting at s_q is a h_q-restricted separating vertex set and hence, this yields a better upper bound, as $|S_s(1)| \leq |S|$. The same holds for $|S_t(1)|$. Therefore, $\rho_{h_q}(s_q, t_q) \leq min\{|S_s(1)|, |S_t(1)\}$.

Furthermore, we can state the following. Informally speaking, if the cardinality of some level is smaller than k_q, then $k_q > \rho_{h_q}(s_q, t_q)$ and therefore, there are no k_q node disjoint paths between s_q and t_q with length at most h_q, given there are no paths which are shorter than the actual level or have equal length. E.g. if there are three paths with length 4 and one path with length 3 and these paths are pairwise node disjoint, then in S there are only three nodes in level 3 starting from s_q, i.e. $|S_s(3)| = 3$, and three nodes in level 3 starting from t_q, i.e. $|S_t(3)| = 3$. As $4 > 3$, this would suggest, that there are no four node disjoint paths, but there are. We somehow have to take the one shorter path into account. This is done via $buf_s(l)$ and $buf_t(l)$ as defined before, which can be seen in Lemma 3.12.

Lemma 3.12. *If there is a l, $1 \leq l \leq h_q - 1$, such that $k_q > |S_s(l)| + buf_s(l)$ or $k_q > |S_t(l)| + buf_t(l)$, then there are no k_q node disjoint paths between s_q and t_q with length at most h_q.*

Proof. From Corollary 3.11 we know, that the set S is a h_q-restricted separating vertex set for s_q and t_q. But there exist smaller h_q-restricted separating vertex sets for s_q and t_q, e.g. the set of nodes, where each of the pairwise node disjoint paths has exactly one node in this set. This is actually the smallest possible h_q-restricted separating vertex set for s_q and t_q.

Further h_q-restricted separating vertex sets for s_q and t_q are the sets $S_s(1)$ and $S_t(1)$, as every possible path of the maximum set of pairwise h_q-bounded node disjoint paths must contain one node, which is adjacent to s_q and one node which is adjacent to t_q. As k_q denotes the required number of pairwise node disjoint paths between s_q and t_q with length at most h_q, k_q must be smaller than or equal to the actual maximum number of such paths, i.e. $k_q \leq \rho_{h_q}(s_q, t_q)$. Therefore, for any h_q-restricted separating vertex set S_{h_q} for s_q and t_q, $k_q \leq \rho_{h_q}(s_q, t_q) \leq |S_{h_q}|$. Furthermore, $buf_s(1) = buf_t(1) = 0$ always holds. Hence, if $k_q > |S_s(1)|$ or $k_q > |S_t(1)|$, then $k_q > \rho_{h_q}(s_q, t_q)$ and therefore no k_q pairwise node disjoint paths between s_q and t_q with length at most h_q are possible.

The set $S_s(2)$ must not be a h_q-restricted separating vertex set for s_q and t_q, as there could be some path, which has length only 2. Now let np denote the number of pairwise disjoint paths with length 2 which are contained in the maximum set of pairwise h_q-bounded node disjoint paths between s_q and t_q. Then, clearly, there are no k_q pairwise node disjoint paths between s_q and t_q with length at most h_q, if $k_q - np > |S_s(2)|$, as then $k_q > \rho_{h_q}(s_q, t_q)$.

For the general case, the set $S_s(l)$ must not be a h_q-restricted separating vertex set for s_q and t_q, as in the maximum set of pairwise h_q-bounded node disjoint paths between s_q and t_q there could be paths, which have length smaller or equal to l. An upper bound for the number of such paths is the value given by $buf_s(l)$, as defined before. Therefore, in consequence of Corollary 3.8, $\rho_{h_q}(s_q, t_q) - buf_s(l) \leq |S_s(l)|$, in other words $\rho_{h_q}(s_q, t_q) \leq |S_s(l)| + buf_s(l)$. Hence, if $k_q > |S_s(l)| + buf_s(l)$ for any l, $1 \leq l \leq h_q - 1$, then $k_q > \rho_{h_q}(s_q, t_q)$, which means that there are no k_q node disjoint paths between s_q and t_q with length at most h_q.

The same holds of course for the set $S_t(l)$ with regard to $buf_t(l)$, which concludes the proof. □

Unfortunately, the opposite to Lemma 3.12 must not be true and therefore, we have no polynomial time decision procedure for testing feasibility, given the solution is represented as a subgraph. But with Algorithm 3.9 we now have a quite good upper bound for $\rho_{h_q}(s_q, t_q)$ and can check k_q against this bound.

Theorem 3.13. *Algorithm 3.9 is correct and its runtime is* $O(|V| \cdot (|V| + |E|))$.

Proof. The correctness of Algorithm 3.9 immediately follows from Corollary 3.11 and Lemma 3.12.

The runtime of the BFS variant is the same as for the simple BFS, i.e. $O(|V| + |E|)$ [17]. As in the worst case, in every iteration of the repeat-until loop only one node is deleted until in the end all nodes are deleted and the graph consists of only one block, the repeat-until loop has at most $|V| - 2$ iterations. Hence, the overall runtime is $O(|V| \cdot (|V| + |E|))$. □

We have presented an algorithm for an advanced feasibility check regarding one specific commodity. We will now extend it to an algorithm for an advanced feasibility check regarding the whole subgraph and all commodities.

Algorithm 3.13 AdvancedFeasibilityCheck(G, Q)

Input: A graph $G = (V, E)$ and a set of commodities Q
Output: $true$, if the advanced check was successful, $false$ otherwise

```
for all q ∈ Q do
   if k_q > 1 ∧ AdvancedFeasibilityCheck(G, q) = false then
      return false
   end if
end for
return true
```

Theorem 3.14. *Algorithm 3.13 is correct and its runtime is* $O(|Q| \cdot |V| \cdot (|V| + |E|))$.

Proof. The correctness of Algorithm 3.13 immediately follows from the correctness of Algorithm 3.9.

As Algorithm 3.9 is invoked exactly $|Q|$ times, the runtime of Algorithm 3.13 is $O(|Q| \cdot |V| \cdot (|V| + |E|))$. □

For the HESND the advanced feasibility check works similar. Also the graph theoretical background, i.e. H-restricted separating edge set SE_H for x and y and the maximum number of H-bounded edge disjoint paths $\rho_{eH}(x, y)$, yields a similar Corollary, i.e. $\rho_{eH}(x, y) \leq |SE_H|$.

Also for the HESND we first number the nodes according to their level in the BFS trees starting from s_q and t_q and compute the node induced subgraph G'. In this subgraph we now construct the set S as the set of edges, which in principal can be on paths from s_q to t_q with length at most h_q, where we only take into account edges which go from a node with label x to a node with label y if $x < y$. All edges, which are not accounted for in this step are omitted from G'. Edges which were taken into account are then labelled with $x + 1$, with other words, an edge is then in the level $x + 1$. buf_s and buf_t are defined exactly as for the node-disjointness version.

The advanced feasibility test now works similar to Lemma 3.12, i.e. if there is a l, $1 \leq l \leq h_q - 1$, such that $k_q > |SE_s(l)| + buf_s(l)$ or $k_q > |SE_t(l)| + buf_t(l)$, then there are no k_q edge disjoint paths between s_q and t_q with length at most h_q. The proof is similar to the proof of Lemma 3.12 and therefore easy to show. Hence, we skip the details here.

3.2.3 Testing feasibility exactly

Now we present an algorithm that tests for one commodity, if a feasible solution is possible per se. As this problem is *NP*-complete, we are not able to give a polynomial time algorithm, unless $P = NP$.

First, we will describe the idea behind the algorithm. For testing feasibility regarding one commodity, we only have to take into a account the nodes, which are in S, as constructed by Algorithm 3.9. This means, the search space is restricted to the graph induced by S. We then perform a depth-restricted DFS, restricted to the maximum level h_q. W.l.o.g. we number the nodes, starting with $1, 2, 3, \ldots$, except for the nodes s_q and t_q. For each node in the DFS-tree we maintain a bitstring. Every node v_i in the DFS-tree now gets a label $p(v_i)$ (the bitstring), where the n-th bit is set, if the node v_n is the actual node or a parent of v_i in the

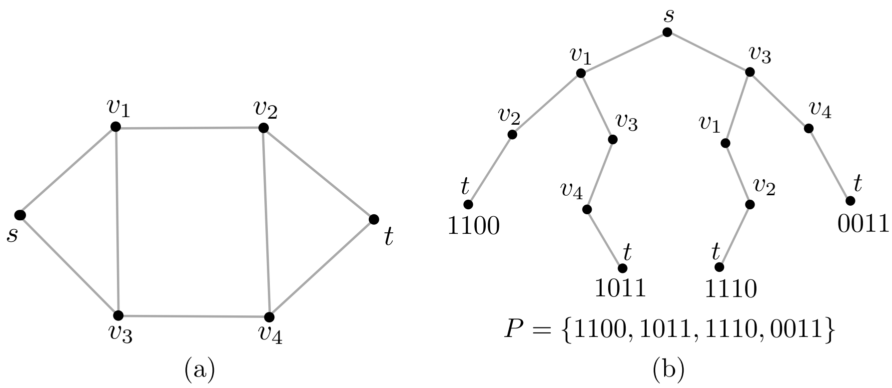


Figure 3.4: A graph G (a) and the corresponding path tree (b).

DFS-tree. Now let P be a set of bitstrings. Whenever in the tree we encounter the node t_q, we add the bitstring of its parent to the set P. Such a bitstring corresponds to the node-set of a path from s_q to t_q with length at most h_q. For a better understanding this tree and the labeling is depicted in Figure 3.4. In the end, the set P contains all possible paths from s_q to t_q with length at most h_q. In the next step we have to find the maximum cardinality of a set of disjoint bitstrings, this then computes $\rho_{h_q}(s_q, t_q)$. In the end we check if $k_q \leq \rho_{h_q}(s_q, t_q)$, then a feasible solution is possible.

Algorithm 3.14 shows the exact feasibility test, as outlined before. We will in the following present the subroutines for this algorithm.

Algorithm 3.14 TestFeasibilityExactly(G, q)

Input: A graph G and a commodity q

Output: $true$, if G allows a feasible solution to q, $false$ otherwise

```
G' := ComputeGraphInducedByS(G, q)
P := ConstructPathsAsBitsets(G', q)
val := CoverLengthTwo(P)
if val < k_q then
   return TFSearch(P, val, q)
end if
return true
```

The set of bitstrings P is constructed by Algorithms 3.15 and 3.16, where & denotes the bitwise-and operator and | denotes the bitwise-or operator. In the example graph from Figure 3.4(a) there are more possible paths from s_q to t_q with length at most h_q than the four paths depicted in Figure 3.4(b). But if e.g. we cannot find a feasible solution with the path $\{s, v_1, v_2, t\}$, then we certainly can not find a feasible solution with the path $\{s, v_1, v_2, v_4, t\}$, although this path would fulfill the length requirement. That this set P in fact contains all reasonable paths from s_q to t_q with length at most h_q, which we need for finding a feasible solution, is shown by the following Lemma.

Algorithm 3.15 ConstructPathsAsBitsets(G, q)

Input: A graph G and a commodity q

Output: set of all possible paths from s_q to t_q with length at most h_q

```
P := ∅
initp(s_q) := 0
initp(t_q) := 0
for i := 1 to |V| − 2 do
    set i-th bit in initp(v_i)
end for
CPSearch(s_q, 0)
return P
```

Algorithm 3.16 CPSearch(v, lvl)

Input: A node v and a natural number lvl

Output: A set of bitstrings representing all possible paths from s_q to t_q with length at most h_q

```
if t_q ∈ N(v) then
    P := P ∪ {p(v)}
else
    if lvl ≠ h_q − 1 then
        for all v_i ∈ N(v) with p(v_i) & p(v) ≠ 0 do
            p(v_i) := initp(v_i) | p(v)
            lvl := lvl + 1
            CPSearch(v_i, lvl)
        end for
    end if
end if
```

Lemma 3.15. *P, as constructed by Algorithms 3.15 and 3.16, is a set of bitstrings, that represents all reasonable paths from s_q to t_q with length at most h_q, which we need for finding a feasible solution and hence, for computing $\rho_{h_q}(s_q, t_q)$.*

Proof. Assume, there is a path p which is part of the only feasible solution and $p \notin P$. Algorithm 3.16 stops whenever the neighborhood of a node encountered in the search contains t_q or the length of a path would be longer than h_q. The latter condition does not truncate any feasible paths, whereas the former condition could. Therefore, p must be a path, in which some node - except for the last one - is adjacent to t_q, otherwise this path would be in P. But replacing p with this shorter path changes nothing in the feasibility of the solution and therefore contradicts the assumption, that p must be part of the only feasible solution. Hence, P, as constructed by Algorithms 3.15 and 3.16 represents all paths, we need for finding a feasible solution and hence, for computing $\rho_{h_q}(s_q, t_q)$. □

Algorithm 3.17 CoverLengthTwo(P)

Input: A set of bitstrings P

Output: number of bitstrings where only one bit is set

```
val := 0
for all p ∈ P do
    if only one bit is set in p then
        val := val + 1
        for all r ∈ P with r ≠ p do
            if p & r ≠ 0 then
                delete r from P
            end if
        end for
        delete p from P
    end if
end for
return val
```

That with Algorithm 3.17 we can speed up our search by restricting the search space in the set of bitstrings is due to Lemma 3.16.

Lemma 3.16. *If there is a feasible solution, then there is also a feasible solution which contains all possible paths of length* 2.

Proof. Let P_1 be a feasible solution, i.e. a set of more than or equal to k_q node disjoint paths, fulfilling the hop constraint. Observe that each possible path of length 2 can only be non-disjoint to at most one path in P_1 and every path of length 2 is node disjoint to every other path of length 2, as we consider only simple graphs. Let $P_2 = P_1$. Then, for all possible paths of length 2 we put a path p with length 2 into P_2 instead of its non-disjoint equivalent from P_1 or instead of an arbitrary path from P_1, if there is no non-disjoint path to p. The resulting set P_2 is then by construction a set that contains more than or equal to k_q node disjoint paths and replacing paths with shorter paths does not make a solution

Algorithm 3.18 TFSearch(P, val, q)

Input: A set of bitstrings P, a natural number val and a commodity q
Output: $true$, if in P there are k_q disjoint bitstrings, $false$ otherwise

if $val = k_q$ **then**
  if $P \neq \emptyset$ **then**
    return $true$
  end if
  return $false$
end if
$val := val + 1$
for $i := 1$ **to** $|P|$ **do**
  $P' := SetOfDisjointBitstrings(P, p_i)$
  if $|P'| \geq k_q - val$ **then**
    if $TFSearch(P', val, q) = true$ **then**
      return $true$
    end if
  end if
end for
return $false$

infeasible. Hence, we have a solution which contains all possible paths of length 2. □

From the construction of P in Algorithms 3.15 and 3.16 follows, that every possible path of length 2 is actually found. Let val denote the number of paths with length 2 in P. If in the following we consider only the paths, which are disjoint to the paths with length 2, we have to search only for $k_q - val$ more paths in this truncated set. If we find $k_q - val$ disjoint paths in this truncated set, then by Lemma 3.16 we have a feasible solution and hence, this allows us to further restrict the search space.

Lemma 3.17. *The maximum cardinality of a set of disjoint bitstrings computes* $\rho_{h_q}(s_q, t_q)$.

Proof. Two paths p and q are node disjoint if the representing bitsets do not share a node, i.e. if $p \,\&\, r = 0$, where & denotes the bitwise-and operator. Hence, if we find the maximum number of disjoint bitsets, this is equivalent to the maximum number of node disjoint paths between s_q and t_q with length of most h_q, i.e. $\rho_{h_q}(s_q, t_q)$. □

Algorithm 3.19 SetOfDisjointBitstrings(P, p_i)

Input: A set of bitstrings P and a bitstring p_i

Output: Subset of P where all bitstrings are disjoint to p_i

```
P' := ∅
for j := i to |P| do
    if p_i & p_j = 0 then
        P' := P' ∪ {p_j}
    end if
end for
return P'
```

Algorithm 3.18 tests, if there are at least k_q disjoint bitsets in P. With Algorithm 3.18 we do not actually compute the exact value of $\rho_{h_q}(s_q, t_q)$, but we rather check, if $k_q \leq \rho_{h_q}(s_q, t_q)$ and therefore a feasible solution is possible. This approach can be faster than actually computing the exact value of $\rho_{h_q}(s_q, t_q)$.

Theorem 3.18. *Algorithm 3.14 is correct and its runtime is in the worst case not polynomially bounded.*

Proof. The correctness of Algorithm 3.14 immediately follows from Lemma 3.15, Lemma 3.16 and Lemma 3.17.

As we enumerate all possible paths and these can be in the worst case exponentially many, the runtime is in the worst case clearly not polynomially bounded. □

For the HESND we have to adapt Algorithms 3.15 and 3.16. In this case, the bitsets store not the nodes, but the edges of a path. Therefore we have to set *initp*(e_i) for edges as well as storing the edges - and not the nodes - in the set of bitstrings representing all possible paths from s_q to t_q with length at most h_q. The rest of the exact feasibility test stays the same. Hence, in the end it also checks if $k_q \geq \rho_{eh_q}(s_q, t_q)$.

3.2.4 Complete feasibility test

As we have developed all the components, we need for a complete feasibility test, we will now present the combination of all these components. Algorithm 3.20 is a complete feasibility test for a single commodity, whereas Algorithm 3.21 is a complete feasibility test for the whole set of commodities Q.

Algorithm 3.20 TestFeasibility(G, q)

Input: A (solution) graph G and a commodity q
Output: $true$, if G allows a feasible solution, $false$ otherwise

if $QuickFeasibilityCheck(G, q)$ **then**
  if $k_q > 1 \wedge AdvancedFeasibilityCheck(G, q)$ **then**
    return $TestFeasibilityExactly(G, q)$
  end if
  return $true$
end if
return $false$

Theorem 3.19. *Algorithm 3.20 is correct and its runtime is constant, if the quick check failed, it is $O(|V|\cdot(|V|+|E|))$, if the advanced check failed and otherwise in the worst case not polynomially bounded.*

Proof. The correctness and the runtime of Algorithm 3.20 immediately follows from the correctness and runtime of Algorithm 3.8, as well as Theorem 3.13 and Theorem 3.18. □

Algorithm 3.21 TestFeasibility(G, Q)

Input: A (solution) graph G and a set of commodities Q
Output: $true$, if G allows a feasible solution, $false$ otherwise

if $QuickFeasibilityCheck(Q) \wedge AdvancedFeasibilityCheck(G, Q)$ **then**
  for all $q \in Q$ **do**
    if $TestFeasibilityExactly(G, q) = false$ **then**
      return $false$
    end if
  end for
  return $true$
end if
return $false$

Theorem 3.20. *Algorithm 3.21 is correct and its runtime is $O(|Q|)$, if the quick check failed, it is $O(|Q| \cdot |V| \cdot (|V| + |E|))$, if the advanced check failed and otherwise in the worst case not polynomially bounded.*

Proof. The correctness and the runtime of Algorithm 3.21 immediately follows from the correctness and runtime of Algorithm 3.7, as well as Theorem 3.14 and Theorem 3.18. □

3.3 Testing feasibility on a set of paths

Now assume, our solution is given as a set of paths P. Every path in this set is of the following format. The first node is the starting node s_q of some commodity and the last node is the corresponding target node t_q. All paths starting at some s_q are pairwise disjoint, in order to simplify the feasibility check and because the algorithms we develop, which yield as a result a set of paths, always give a set of pairwise disjoint paths. Testing feasibility is now easy, as we only have to count the paths from s_q to t_q and check, if they fulfill the length requirement. An algorithm for testing the feasibility given one commodity is presented in Algorithm 3.22. An algorithm for testing the feasibility given a set of commodities is presented in Algorithm 3.23. These two algorithms can as well be easily adapted to test feasibility for the variant with individual hop limits.

Algorithm 3.22 TestFeasibility(P, q)

Input: A set of paths P and a commodity q
Output: $true$, if P allows a feasible solution, $false$ otherwise

```
count := 0
for all p ∈ P do
   if (first node is s_q ) ∧ (last node is t_q) ∧ l(P) ≤ h_q then
      count := count + 1
   end if
end for
return count ≥ k_q
```

Algorithm 3.23 TestFeasibility(P, Q)

Input: A set of paths P and a set of commodities Q
Output: $true$, if G allows a feasible solution, $false$ otherwise

```
for all q ∈ Q do
   if TestFeasibility(P, q) = false then
      return false
   end if
end for
return true
```

Theorem 3.21. *Algorithm 3.22 is correct and its runtime is $O(|P|)$.*

Proof. The correctness of Algorithm 3.22 is easy to see. As we check all paths $p \in P$, the runtime is $O(|P|)$. □

Theorem 3.22. *Algorithm 3.23 is correct and its runtime is $O(|Q| \cdot |P|)$.*

Proof. The correctness of Algorithm 3.23 immediately follows from the correctness of Algorithm 3.22. As Algorithm 3.22 is invoked exactly $|Q|$ times, therefore the runtime is $O(|Q| \cdot |P|)$. □

3.4 Solving one single commodity heuristically

As already stated earlier, solving even one single commodity with a hop limit greater than 4 is already *NP*-complete. In the case that $k_q = 1$, we can conduct a simple shortest path search, taking the hop limit into account. For $k_q > 1$, we will in the following present three heuristics for this general problem, two of them based on the exact feasibility test and therefore with a not polynomially bounded runtime in the worst case. But as we have developed algorithms to restrict the search space, this two approaches should nevertheless work fast on average. The third heuristic produces in some cases no solution, but does not depend on the feasibility test. In the case, this heuristic does not yield a solution, we can solve it with another heuristic as a kind of fallback strategy, in order to get always a feasible solution here too, if a feasible solution is possible. All three heuristics are only executed, if $k_q > 1$.

3.4.1 Special case $k_q = 1$

For the special case, that $k_q = 1$, we use a solution technique called dynamic programming [52]. The use of dynamic programming for a related problem, the constrained shortest path problem, was outlined in [2, 54]. Our dynamic program for the shortest path problem with hop constraint looks as follows:

$$\begin{aligned} d_{s_q}(0) &:= 0 \\ d_j(h) &:= min\{d_j(h-1), min_k\{d_k(h-1) + c_{kj}\}\} \end{aligned}$$

This dynamic program is computed with Algorithm 3.24, which gives the optimal solution, under the assumption that $comp(s_q) = comp(t_q)$. W.l.o.g. we can assume this, as otherwise the quick check would have already failed. The optimal solution value is stored in $d_{t_q}(h_q)$ and the path can be constructed from that. Therefore we store with every $d_j(h)$ also the predecessor called $pred_j(h)$.

$$pred_j(h) := \begin{cases} j & \text{if } d_j(h-1) \leq min_k\{d_k(h-1) + c_{kj}\}, \\ k & \text{otherwise.} \end{cases}$$

Theorem 3.23. *Algorithm 3.24 computes the shortest path from s to t with length at most H, and its runtime is $O(|V|^2 \cdot H)$.*

Proof. The correctness of Algorithm 3.24 follows from the correctness of the dynamic program. At first glance, the runtime appears to be $O(|V| \cdot H)$, but a part of the runtime complexity is hidden in the computation of $min_k\{d_k(h-1) + c_{kj}\}$. Here all adjacent nodes are checked and therefore the runtime is in the worst case $O(|V|^2 \cdot H)$. □

Algorithm 3.24 ShortestHopConstrainedPath(G, s, t, H)

Input: A graph G, two nodes s and t and a hop limit H
Output: The shortest path between s and t with at most h edges

```
Initialize all d_j(h) with ∞
d_s(0) = 0
for h := 1 to H do
   for all j ∈ V do
      if d_j(h − 1) ≤ min_k{d_k(h − 1) + c_kj} then
         d_j(h) := d_j(h − 1)
         pred_j(h) := j
      else
         d_j(h) := min_k{d_k(h − 1) + c_kj}
         pred_j(h) := k
      end if
   end for
end for
return Path as obtained by the predecessors starting with pred_t(H)
```

So, given this algorithm, it is now easy to give an algorithm for the special case that $k_q = 1$, as can be seen in Algorithm 3.25.

Algorithm 3.25 SolvingSingleCommodity_kIsOne(G, q)

Input: A graph G and a commodity q, where $k_q = 1$
Output: A feasible solution to q

```
G' := ComputeGraphInducedByS(G, q)
return ShortestHopConstrainedPath(G', s_q, t_q, h_q)
```

Theorem 3.24. *Algorithm 3.25 computes the shortest path from s_q to t_q with length at most h_q, and therefore solves the special case $k_q = 1$ to optimality.*

Proof. The correctness of Algorithm 3.25 immediately follows from the correctness of Algorithm 3.24. □

After having a solution technique for the special case $k_q = 1$, we present in the following three solution techniques that are able to solve the general case, i.e. $k_q > 1$. We further discuss heuristic algorithms for solving node-disjointness commodities. By adapting these algorithms, they can also be used for edge-disjointness commodities and commodities with individual hop limits, as well as for the prize collecting variant. As adapting them is not difficult, we spare the details here.

3.4.2 Heuristic 1 (SH1)

Algorithm 3.26 SolvingSingleCommodity_Heuristic1(G, q)

Input: A graph G and a commodity q

Output: A feasible solution to q, $\emptyset$ otherwise

```
G' := ComputeGraphInducedByS(G, q)
Psol := ∅
P := ConstructPathsAsBitsets(G', q)
val := SSC_CoverLengthTwo(P, Psol)
if val < k_q then
   if SSC_TFSearch(P, val, q, Psol) then
      return Psol
   else
      return ∅
   end if
end if
return PSol
```

The first heuristic is based on the observation, that by testing the feasibility for one commodity we could take the paths which in the end yield feasibility and hence, we have a feasible solution. This is done in Algorithm 3.26, which is a variant of Algorithm 3.14. Algorithm 3.26 returns a set of disjoint paths. From that we can construct the solution as a subgraph, if required. This solution is minimal, as we can not delete any edge without rendering the solution infeasible.

Algorithm 3.27 SSC_CoverLengthTwo($P, PSol$)

Input: A set of bitstrings P and a set of paths $PSol$

Output: number of bitstrings where only one bit is set

```
val := 0
for all p ∈ P do
   if only one bit is set in p then
      PSol := PSol ∪ {path represented by bitstring p}
      val := val + 1
      for all r ∈ P with r ≠ p do
         if p & r ≠ 0 then
            delete r from P
         end if
      end for
      delete p from P
   end if
end for
return val
```

Algorithm 3.28 SSC_TFSearch($P, val, q, PSol$)

Input: A set of bitstrings P, a natural number val, a commodity q and a set of paths $PSol$

Output: $true$, if in P there are k_q disjoint bitstrings, $false$ otherwise

```
if val = k_q then
   if P ≠ ∅ then
      return true
   end if
   return false
end if
val := val + 1
for i := 1 to |P| do
   P' := SetOfDisjointBitstrings(P, p_i)
   if |P'| ≥ k_q − val then
      PSol := PSol ∪ {path represented by bitstring p_i}
      if TFSearch(P', val, q, PSol) = true then
         return true
      end if
   end if
end for
return false
```

Most subroutines are the same as for the exact feasibility test in Algorithm 3.14, except for $SSC\_CoverLengthTwo(P, PSol)$ and $SSC\_TFSearch(P, val, q, PSol)$.

Algorithm 3.27 is a variant of Algorithm 3.17 and Algorithm 3.28 is a variant of Algorithm 3.18. In both algorithms additionally the paths in the feasible solution are stored. Hence, we can return the paths of the feasible solution, if there is one.

Theorem 3.25. *Algorithm 3.26 returns a feasible solution, if G allows a feasible solution, and its runtime is in the worst case not polynomially bounded.*

Proof. The correctness and runtime of Algorithm 3.26 immediately follows from the correctness and runtime of Algorithm 3.14 and hence, Theorem 3.18. □

3.4.3 Heuristic 2 (SH2)

The second heuristic works as follows. To find a feasible solution, we only have to take into account the graph G' induced by S, as constructed already in Algorithm 3.9. Then the edges are sorted increasingly according to their cost. In every iteration the cheapest edge is inserted, which is incident to at least one node of the current solution, until a feasible solution is reached. Furthermore, in order to get at least k_q different paths, we need k_q edges, which start at s_q and k_q edges, which start at t_q. Hence, in the beginning we start with the k_q "cheapest" edges that are incident to s_q and additionally with the k_q "cheapest" edges that are incident to t_q.

The feasibility test in line 3 of Algorithm 3.31 is very fast, as long as s_q and t_q are in different components or blocks of $GSol$, see Algorithm 3.20 and Theorem 3.19 for further details.

In the end, we conduct some sort of "back tracking", i.e. we successively delete all nodes with $d(v) = 1$, as they are not relevant for any solution. Nodes on paths

Algorithm 3.29 SolvingSingleCommodity_Heuristic2(G, q)

Input: A graph G and a commodity q
Output: A feasible solution to q, $\emptyset$ otherwise

```
G' := ComputeGraphInducedByS(G, q)
if TestFeasibility(G', q) then
   return SSC_Edge(G', q)
end if
return ∅
```

between s_q and t_q always have a node degree $d(v) > 1$, otherwise the path would never reach its destination. Also, we can delete all nodes, which are not reachable from s_q or t_q, as they also do not build up the solution. Also in this case, the solution is minimal after back-tracking. But here the solution is encoded as a subgraph.

Algorithm 3.30 SSC_Edge(G, q)

Input: A graph G and a commodity q
Output: A feasible solution to q

Sort edges in G s.t. $c_{e_1} \leq c_{e_2} \leq ... \leq c_{e_m}$
$GSol := \{k_q$ "cheapest" edges incident to s_q and k_q "cheapest" edges incident to $t_q\}$
while $\neg TestFeasibility(GSol, q)$ **do**
  $e :=$ "cheapest" edge that is incident to at least one node in $GSol$
  $GSol := GSol \cup e$
  $DetermineComponents(GSol)$
  $DetermineBlocks(GSol)$
end while
$SSC\_BackTrack(GSol, q)$
return $GSol$

Algorithm 3.31 SSC_BackTrack(G, q)

Input: A graph G and a commodity q
Output: A subgraph G', which does not contain any node with $d(v) = 1$

$G' := G$
while $\exists v \in V$ with $d(v) = 1$ **do**
  $G' := G' - v$
end while
Delete all nodes, that are not reachable from s_q
return G'

Theorem 3.26. *Algorithm 3.29 returns a feasible solution, if G allows a feasible solution, and its runtime is in the worst case not polynomially bounded.*

Proof. That Algorithm 3.29 returns a feasible solution, if there is one, simply follows from the fact, that only a solution (other than $\emptyset$) is returned, if this solution is feasible. Also the back tracking is not changing the feasibility of the solution. Hence, Algorithm 3.29 returns a feasible solution, if there is one.

The runtime of Algorithm 3.29 immediately follows from the runtime of Algorithm 3.14 and hence, Theorem 3.18. □

3.4.4 Heuristic 3 (SH3)

The third heuristic works as follows. In the first iteration the shortest hop constrained path with hop limit h_q is computed. Then this path is deleted from G and a shortest hop constrained path with hop limit h_q is again computed and afterward deleted from G. This is done at most k_q times. After k_q iterations, we either have a feasible solution or no feasible solution has been found, although there might exist one. The big advantage of this algorithm is the fact that it should be faster because it does not depend on the exact feasibility test. Furthermore, it should work well on graphs, where feasibility is not the problem because k_q disjoint paths with hoplimit h_q can be found easily. The solution is encoded as a set of disjoint paths.

Algorithm 3.32 SolvingSingleCommodity_Heuristic3(G, q)

Input: A graph G and a commodity q

Output: A feasible solution to q, $\emptyset$ otherwise

1: $G' := ComputeGraphInducedByS(G, q)$
2: $GSol := G'$
3: $P := \emptyset$
4: **for** $i := 1$ **to** k_q **do**
5:    $p := ShortestHopConstrainedPath(GSol, s_q, t_q, h_q)$
6:    **if** p is no valid path **then**
7:       **return** $\emptyset$
8:    **end if**
9:    $P := P \cup p$
10:    $GSol := GSol \setminus p$
11: **end for**
12: **return** P

The check, if p is a valid path, in line 6 of Algorithm 3.32 is easy. In the case, no path with the given hoplimit is possible, $d_t(h_q) = \infty$ and therefore the path obtained via $pred_{t_q}(h_q)$ consists only of t_q.

Theorem 3.27. *Algorithm 3.32 returns a feasible solution, if it finds one, and its runtime is in the worst case* $O(k_q \cdot |V|^2 \cdot h_q)$.

Proof. That Algorithm 3.29 returns a feasible solution, if it finds one, is obviously true.

On the one hand, the runtime of Algorithm 3.29 follows from the runtime of Algorithm 3.24 and hence, Theorem 3.23. On the other hand, as this algorithm is invoked at most k_q times, the overall runtime is in the worst case $O(k_q \cdot |V|^2 \cdot h_q)$. □

Algorithm 3.33 SolvingSingleCommodity_Heuristic3_Fallback(G, q)

Input: A graph G and a commodity q

Output: A feasible solution to q, $\emptyset$ otherwise

1: $P := SolvingSingleCommodity\_Heuristic3(G, q)$
2: **if** $P = \emptyset$ **then**
3:    **return** $SolvingSingleCommodity\_HeuristicX(G, q)$
4: **end if**
5: **return** P

As in some cases, Algorithm 3.32 does return $\emptyset$, although a feasible solution would exist, we introduce a fallback strategy. If Algorithm 3.32 returns $\emptyset$, then we re-solve it with one of the other solution algorithms for the single commodity case and therefore can be sure, that finding no feasible solution implies that there is no feasible solution at all. This is shown in Algorithm 3.33, where the X in line 3 stands for any other solution algorithm for the single commodity. Algorithm 3.33 is in the following referred to as SH3F, in order to prevent confusions with Algorithm 3.32, which is referred to as SH3.

Theorem 3.28. *Algorithm 3.33 returns a feasible solution, if G allows a feasible solution, and its runtime is $O(k_q \cdot |V|^2 \cdot h_q)$, if Algorithm 3.32 succeeds, otherwise it is in the worst case not polynomially bounded.*

Proof. That Algorithm 3.33 returns a feasible solution, if G allows a feasible solution follows from Theorem 3.27 and the correctness of the other algorithms for solving a single commodity.

In the case, Algorithm 3.32 succeeds, the runtime follows from Theorem 3.27. Otherwise, the runtime of Algorithm 3.33 immediately follows from the runtime of the other algorithms for solving a single commodity. □

For the HESND we only have to adapt line 10 of Algorithm 3.32, as we delete the edges of the path p from $GSol$ and the nodes remain in the graph.

Chapter 4

Constructive heuristics

In this chapter we present four constructive heuristics. These heuristics will produce initial solutions we can then use in the following chapter for the meta-heuristic approaches.

4.1 Constructive heuristic 1 (CH1)

Algorithm 4.1 ConstructiveHeuristic1(G, Q)

Input: A graph G and a set of commodities Q

Output: A feasible solution, if there exists one, $\emptyset$ otherwise

```
Sort edges s.t. sorted edge lists for blocks are sorted increasingly by the costs
if QuickFeasibilityCheck(G, Q) ∧ TestFeasibility(G, Q) then
    GSol = ∅
    CH1_One(G, Q, GSol)
    CH1_Edge(G, Q, GSol)
    Successively delete "most expensive" edge from GSol, as long as the solution
    stays feasible
    return GSol
end if
return ∅
```

The first constructive heuristic is a generalization from Heuristic 2 for the single commodity case (SH2), based on a greedy approach [52]. At first we will solve all commodities where $k_q = 1$. Then we again add always the cheapest edge, that is incident to at least one node of the current solution. We do not only test one commodity for feasibility, but all commodities together which are in the same block as this edge. Then we successively delete the "most expensive" edge from $GSol$, as long as the solution stays feasible, as some sort of back-tracking. The sorting of the edges works as follows. Instead of maintaining a global sorted edge list, we maintain a sorted edge list for each block, let the list for a block b be denoted by $list_b$ and the i-th edge for a block by $list_b[e_i]$ where $1 \leq i \leq m_b$.

Algorithm 4.2 CH1_One($G, Q, GSol$)

Input: A graph G, a set of commodities Q and a solution graph $GSol$
Output: $GSol$ augmented by the solution to all commodities where $k_q = 1$

for all $q \in Q$ with $k_q = 1$ **do**
    $GSol = GSol \cup SolvingSingleCommodity\_kIsOne(G, q)$
    Mark q as solved
end for
for all blocks b where there is no unsolved commodity left **do**
    Mark b as solved
end for

Algorithm 4.3 CH1_Edge($G, Q, GSol$)

Input: A graph G, a set of commodities Q and a solution graph $GSol$
Output: $GSol$ augmented by the solution to all commodities where $k_q \neq 1$

for all blocks b which are not yet solved completely **do**
    while not all commodites in b are solved completely **do**
        e :="cheapest" edge from $list_b$ that is incident to at least one node in $GSol$
        $GSol := GSol \cup e$
        $DetermineComponents(GSol)$
        $DetermineBlocks(GSol)$
        for all $q \in Q$ with $b \in bl(s_q)$ and q not marked solved **do**
            if $TestFeasibility(GSol, q)$ **then**
                Mark q as solved
                if b has no unsolved commodity left **then**
                    Mark b as solved
                end if
            end if
        end for
    end while
end for

The first subroutine $CH1\_One(G, Q, GSol)$, described in Algorithm 4.2, solves all the commodities where $k_q = 1$ and adds the solutions to the solution graph $GSol$. Every commodity which has a feasible solution in $GSol$ is marked to be solved. In the end, also the blocks, which have no unsolved commodity left, are marked to be solved. The latter can be done efficiently by a counter which stores for each block b, how many commodities are left to be solved, where $b \in bl(s_q)$.

The second subroutine $CH1\_Edge(G, Q, GSol)$, described in Algorithm 4.3, solves the rest of the commodities by successively adding cheapest edges in a block b, which are incident to at least one node of the current solution, until all commodities in b are fulfilled by the solution graph $GSol$. This is done for all blocks.

Theorem 4.1. *Algorithm 4.1 solves all commodities, if G allows a feasible solution.*

Proof. That Algorithm 4.1 returns a feasible solution, if there is one, simply follows from the fact, that only a solution (other than $\emptyset$) is returned, if a feasible solution is possible. The adding of edges is stopped only, if all commodities are solved and this must be possible, as G then allows some feasible solution. Hence, Algorithm 4.1 solves all commodities, if G allows a feasible solution. □

4.2 Constructive heuristic 2 (CH2)

The second constructive heuristic is based on a divide and conquer approach [52]. All commodities are solved by themselves and then from the individual solutions, the solution to all commodities is built by the union of the individual solution graphs. This is described in Algorithm 4.4.

In $SolvingSingleCommodity\_HeuristicX(G, q)$ (see line 7 of Algorithm 4.4), the X stands for every solution algorithm for a single commodity we have developed before, which never results in infeasible solutions, although feasible solutions would be possible. Hence, SH3 without fallback is not an option here. We will in Chapter 6 present computational results for the individual solution algorithms.

Theorem 4.2. *Algorithm 4.4 solves all commodities, if G allows a feasible solution.*

Proof. That Algorithm 4.4 returns $\emptyset$, if one commodity can not be solved, follows from the *if*-statement in line 9 of the algorithm. Otherwise all commodities $q \in Q$

Algorithm 4.4 ConstructiveHeuristic2(G, Q)

Input: A graph G and a set of commodities Q

Output: A feasible solution, if there exists one, $\emptyset$ otherwise

if $QuickFeasibilityCheck(G, Q)$ **then**
    for all $q \in Q$ **do**
        $G' = \emptyset$
        if $k_q = 1$ **then**
            $G' = SolvingSingleCommodity\_kIsOne(G, q)$
        else
            $G' = SolvingSingleCommodity\_HeuristicX(G, q)$
        end if
        if $G' = \emptyset$ **then**
            return $\emptyset$
        end if
        $GSol = GSol \cup G'$
    end for
end if
return $GSol$

were solved and therefore we obtain a solution for all the commodities by the union of all individual solution graphs. Hence, Algorithm 4.4 solves all commodities, if G allows a feasible solution. □

4.3 Constructive heuristic 3 (CH3)

The third constructive heuristic is a more sophisticated variant of the second constructive heuristic, nevertheless it is no pure divide and conquer approach because the individual solutions are not independent of one another any more. After one commodity q is solved, all the edge costs of the edges in the solution graph to q are set to 0. The idea behind this is to enhance the multiple use of edges for more than one commodity. As we set the costs of already used edges to 0, the chance that they are used again for other commodities is greater. Therefore, this small modification should yield better solutions.

This approach can be used for randomization because the solution value should depend on which commodities are to be solved first, if an algorithm for solving a single commodity is used, which is "cost-sensitive". Therefore, SH1 is not a good candidate for randomization. Hence, shaking the order in which the commodities are solved should yield different solution values and solution graphs. We will make use of this in the next chapter, where we want to improve the initial solutions we get by the constructive heuristics.

Also here, regarding $SolvingSingleCommodity\_HeuristicX(G, q)$, the X stands for every solution algorithm for a single commodity we have developed before, which never results in infeasible solutions, although feasible solutions would be possible. We will in Chapter 6 present computational results for the individual solution algorithms too.

Theorem 4.3. *Algorithm 4.5 solves all commodities, if G allows a feasible solution.*

Proof. The correctness of Algorithm 4.5 immediately follows from the correctness of Algorithm 4.4, and hence, Theorem 4.2, as changing the edge costs can not change the fact, that a feasible solution is possible, as feasibility is independent from the edge costs. □

Algorithm 4.5 ConstructiveHeuristic3(G, Q)

Input: A graph G and a set of commodities Q
Output: A feasible solution, if there exists one, $\emptyset$ otherwise

if $QuickFeasibilityCheck(G, Q)$ **then**
    for all $q \in Q$ **do**
        $G' = \emptyset$
        if $k_q = 1$ **then**
            $G' = SolvingSingleCommodity\_kIsOne(G, q)$
        else
            $G' = SolvingSingleCommodity\_HeuristicX(G, q)$
        end if
        if $G' = \emptyset$ **then**
            return $\emptyset$
        end if
        for all $e \in E_{G'}$ **do**
            Set $c_e = 0$
        end for
        $GSol = GSol \cup G'$
    end for
end if
return $GSol$

Algorithm 4.6 ConstructiveHeuristic4(G, Q)

Input: A graph G and a set of commodities Q

Output: A feasible solution, if there exists one, $\emptyset$ otherwise

```
if QuickFeasibilityCheck(G, Q) then
   for all q ∈ Q do
      G' = SolvingSingleCommodity_Heuristic3(G, q)
      if G' = ∅ then
         Postpone solving of q
      end if
      for all e ∈ E_G' do
         Set c_e = 0
      end for
      GSol = GSol ∪ G'
   end for
   for all remaining commodities q do
      G' = ∅
      if k_q = 1 then
         G' = SolvingSingleCommodity_kIsOne(G, q)
      else
         G' = SolvingSingleCommodity_HeuristicX(G, q)
      end if
      if G' = ∅ then
         return ∅
      end if
      for all e ∈ E_G' do
         Set c_e = 0
      end for
      GSol = GSol ∪ G'
   end for
end if
return GSol
```

4.4 Constructive heuristic 4 (CH4)

The fourth constructive heuristic is a combination of CH3 with SH3 (without the fallback) and hence, a slightly more involved variant. Basically, the idea behind it is the same as with CH3. Hence, we use SH3 to solve the commodities one after another. But in case SH3 does not return a solution regarding some commodity

q, we postpone the solving of q. Hence, the edge costs are only re-set, when SH3 returns a solution. In the end, all solutions remaining to be solved are solved using another solution algorithm for a single commodity. This approach is described in Algorithm 4.6.

Theorem 4.4. *Algorithm 4.6 solves all commodities, if G allows a feasible solution.*

Proof. The correctness of Algorithm 4.6 immediately follows from the correctness of Algorithm 4.5 and hence, Theorem 4.3, as it is only a variant of this algorithm. □

Chapter 5

Metaheuristics

In this chapter we present metaheuristic approaches for the Hop Constrained Survivable Network Design Problem. At first we discuss a Variable Neighborhood Descent (VND) with two neighborhood structures. This neighborhoods are called Recalculate Commodity Neighborhood (RCN) and Key-Path Exchange Neighborhood (KPEN). Then the VND is used in a multi-start approach, where we make use of the randomization possibility of CH3 and CH4. Last, but not least, a Greedy Randomized Adaptive Search Procedure (GRASP) is presented, where the greedy CH1 is randomized and afterwards the VND is applied to improve the solution value given by the randomized greedy constructive heuristic.

5.1 Variable neighborhood descent (VND)

In this section, we present a VND [42, 62]. The success of a VND, compared to a simple local search, lies in the applied neighborhood structures as well as their composition. We will in the following present two neighborhood structures and the composition of these neighborhoods. A big advantage is, that for all commodities q with $k_q > 1$ we can do some kind of Variable Neighborhood Decomposition approach, as we only have to take into account the block the commodity q is in and not the whole graph G.

5.1.1 Recalculate commodity neighborhood (RCN)

The RCN is very similar to the Connection Exchange Neighborhood presented in [56] and works as follows. First of all, we have to store the solution graphs to the individual commodities separately. Let the solution graph to a commodity q be denoted by G_q. Then the neighborhood results from deleting the solution to one commodity q, in fact we delete all edges that are part of G_q, but not part of any solution graph to another commodity. This can be done very efficiently by storing the number of solutions an edge is part of, denoted by $ns(e)$.

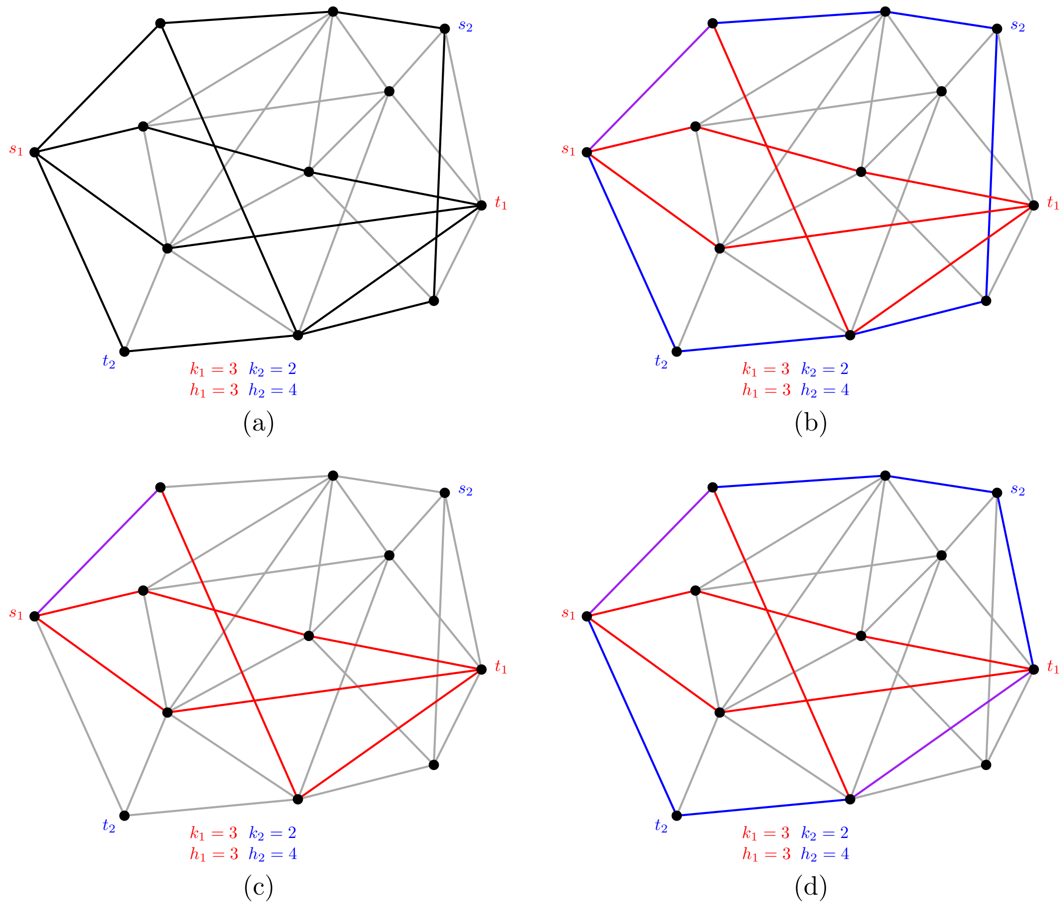


Figure 5.1: Example for an application of the RCN.

After deleting the edges from the overall solution graph $GSol$, the edge costs are re-set in the following way: All edges, which are still part of $GSol$ after deleting the edges, get new cost $c_e = 0$. For all other edges the costs remain the same. Then the commodity is resolved with the changed cost values.

This approach should enforce the multiple use of edges and therefore yield better solution values. This neighborhood does not generate infeasible solutions out of feasible ones. This is obvious, as changing edge costs only does not lead to an infeasible solution when resolving a commodity. Hence, given we start with feasible solutions only, this fact does not change after applying RCN.

An example for the application of RCN is shown in Figure 5.1. The actual solution can be seen in 5.1(a). In Figure 5.1(b), the solution graphs G_q are shown. Figure 5.1(c) gives the remaining graph, where all red and purple edges get cost $c_e = 0$. The best found solution after recalculating the blue commodity is depicted in Figure 5.1(d), where can be seen that now two edges are used in both commodity solutions.

Algorithm 5.1 shows the RCN, where we use a best-improvement strategy.

Algorithm 5.1 RCN($G, Q, GSol$)

Input: A graph G, a set of commodities Q and a solution graph $GSol$
Output: A better solution, $GSol$ otherwise

$d := 0$
$bestsolution := GSol$
for all $q \in Q$ **do**
  $GSol' := GSol$
  Delete all edges from $GSol'$ which are only in G_q
  $c'_e := 0$ for all $e \in GSol'$
  $c'_e := c_e$ for all $e \notin GSol'$
  $G'_q :=$ Resolve commodity with c'_e
  $GSol' := GSol' \cup G'_q$
  $d' := c(GSol) - c(GSol')$
  if $d' > d$ **then**
    $d := d'$
    $bestsolution := GSol'$
  end if
end for
return $bestsolution$

5.1.2 Key-Path exchange neighborhood (KPEN)

This neighborhood structure is inspired by the Key-Path Exchange Neighborhood presented in [55, 56]. This kind of neighborhood structure is established for the Steiner Tree Problem, for further information see e.g. [60]. This neighborhood structure is based on the notion of key paths.

Definition 5.1 (Key Node). *A node v with $d(v) > 2$ in the solution graph is called a key node.*

Definition 5.2 (Key Path). *A path P is called a key path, if all inner nodes have degree $d(v) = 2$ and are not s_q or t_q of some commodity, whereas its starting point and its end point are either key nodes or s_q or t_q of some commodity.*

Now, instead of recalculating a whole commodity, we recalculate a key path on a modified graph. The exchange cannot be done as easily as for the Capacitated Connected Facility Location [55] or the Last Mile Problem in Fiber Optic Networks [56], as we have to take the restrictions of all affected commodities into account. This means, on the one hand, we must ensure that recalculating a key path does not change the number of pairwise disjointness paths in the solution. On the other hand, we must ensure that the new solution does not violate the hop constraint after recalculating a key path.

Therefore, before recalculating a key path and exchanging it, in case it yields a better solution value, we need to modify the graph G in the following way. All commodities, where the key path P is a part of G_q, must be deleted from G. This yields a new graph G'. Hence, it is not possible that the recalculated key path can make the solution infeasible, as we are not allowed to use the edges or nodes which could endanger the disjointness. The test, if a key path is a part of G_q can be done very efficiently by use of Lemma 5.3 and Corollary 5.4.

Lemma 5.3. *If one edge of a key path P is part of G_q, then P is as a whole a part of G_q.*

Proof. Assume, one edge of a key path P is part of G_q, but P is not as a whole a part of G_q. Therefore, there are two edges e_1 and e_2, which are both part of P and w.l.o.g. $e_1 \in G_q$ and $e_2 \notin G_q$. As P is per assumption a key path, all inner nodes v must have $d(v) = 2$, with other words, a key path never has forks. As the solution graphs G_q, constructed by our solution algorithms, are always minimal, i.e. no edge can be deleted without rendering the solution graph infeasible, it follows that the whole path must be part of G_q, if at least one of its edges is a part of G_q. □

Corollary 5.4. *It suffices to take only one edge of P for the check, if P is a part of G_q.*

Proof. This obviously follows from Lemma 5.3. □

Algorithm 5.2 KPEN$(G, Q, GSol)$

Input: A graph G, a set of commodities Q and a solution graph $GSol$
Output: A better solution, $(\emptyset, \emptyset)$ otherwise

$d := 0$
$bestsolution := (\emptyset, \emptyset)$
for all every key path $P = \{v_1, ..., v_2\}$ **do**
    $G' := G \setminus \{$ all G_q, where P is a part of $\} \cup P$
    $c'_e := 0$ for all $e \in GSol \cap \{G' \setminus P\}$
    $c'_e := c_e$ for all $e \notin GSol \cap \{G' \setminus P\}$
    $P' := ShortestHopConstrainedPath(G', v_1, v_2, H_P)$
    $d' := c(P) - c(P')$
    if $d' > d$ **then**
        $d := d'$
        $bestsolution := (P, P')$
    end if
end for
return $bestsolution$

As we now have this modified graph G', we set the edge costs in the following way. All edges, which are part of $GSol$ and are still in G' are set to $c'_e = 0$ and for all other edges of G' the costs remain the same, i.e. $c'_e = c_e$. Given the key path P from v_1 to v_2, a hop constrained shortest path between v_1 and v_2 is computed on the modified graph G' with the modified edge costs c'. Hence, edges which are already part of any G_q, for which P is not a part of, have cost $c_e = 0$ and therefore this should enlarge the multiple use of edges without rendering the solution infeasible.

But which hop limit should we use therefore? Applying a too big hop limit here can yield infeasible solutions, when the sub-paths are stuck together. Applying a too small hop limit can result in no improvements at all. We have of course upper and lower bounds for this hop limit H_P. As we are starting from feasible solutions only, a lower bound is the length of the key path P we try to recalculate, i.e. $H_{min} = l(P)$. An upper bound is the smallest hop limit of all commodities q, where P is a part of (let us call this set Q_P), i.e. $H_{max} = min\{h_q \mid q \in Q_P\}$. But we do not have to consent ourselves to upper and lower bounds because computing the exact (remaining) hop limit is an easy task.

The exact hop limit for the new path can be computed as follows. If we know how many hops we have already used to get to the two endpoints v_1 and v_2 of the key path P for some commodity q, let us denote this number by $used(P, q)$, then the remaining hop limit H_P is simply the difference between h_q and this value. Computing this value is an easy task because we only must take into account the distance from s_q and t_q. So either the used hops are $ds(v_1) + dt(v_2)$ or $ds(v_2) + dt(v_2)$, where ds and dt refer to the actual solution graph G_q. We can take then the minimum of those two values, i.e. $used(P, q) = min\{ds(v_1) + dt(v_2), ds(v_2) + dt(v_1)\}$. Hence, $H_P = min\{h_q - used(P, q) \mid q \in Q_P\}$.

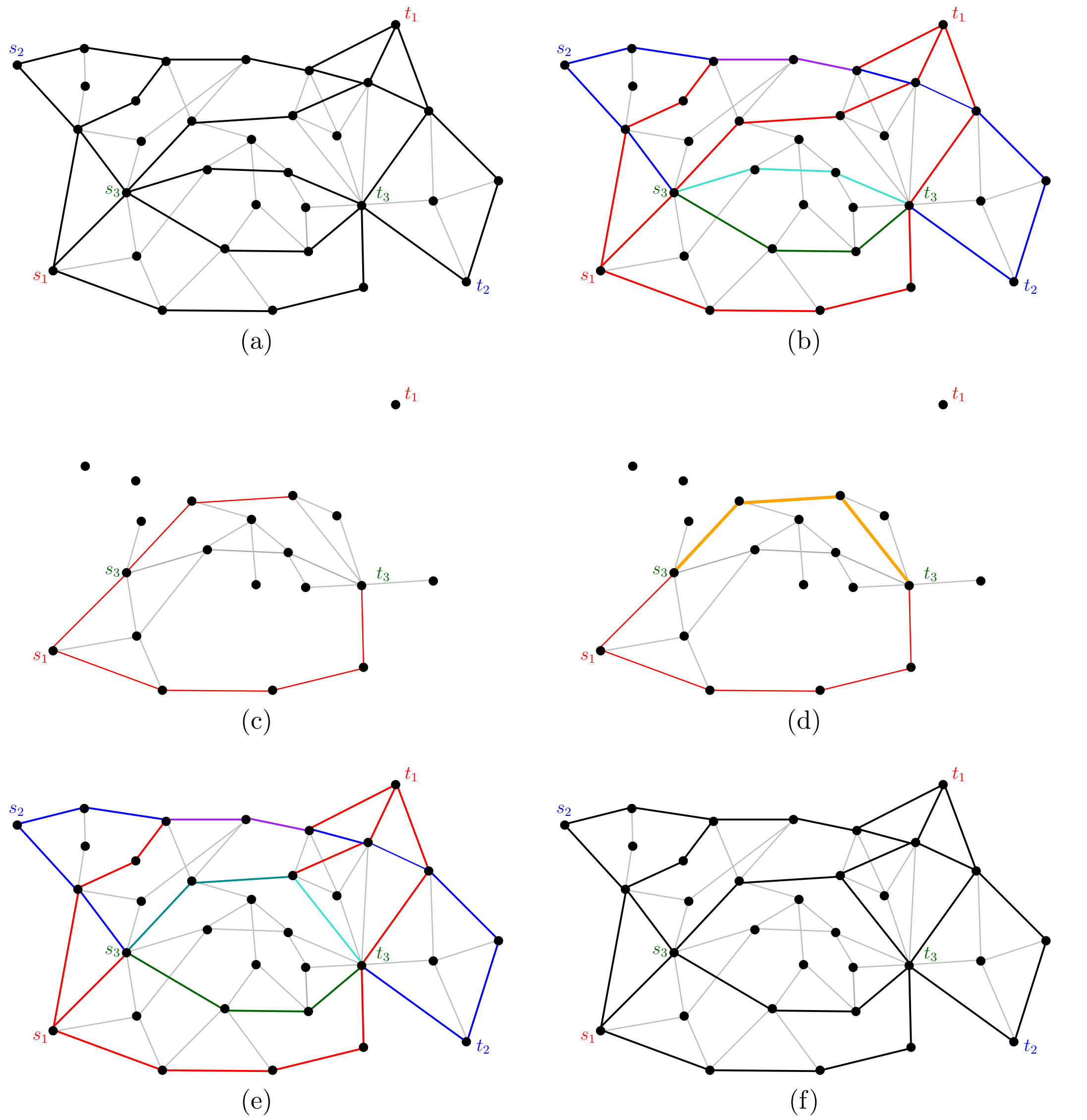


Figure 5.2: Example for an application of the KPEN.

Figure 5.2 shows an application of the KPEN. Figure 5.2(a) depicts the current solution to three commodities. In Figure 5.2(b) the solution graph is split into the solution graphs of the single commodities, which are colored according to the commodities, where purple colored edges are used for the red and the blue commodity and the turquoise edges are used for the blue and the green commodity. The turquoise path is also the key-path we aim to exchange in this application of the KPEN. Figure 5.2(c) shows the residual graph after deleting all nodes and edges, which belong to the green or blue commodity (as the turquoise path is a part of them). All edges which are colored red in this residual graph get edge cost $c'_e = 0$. Then the path is computed with the new edge costs. This new path, which fulfills the requirements and is supposed to have less costs, is shown in Figure 5.2(d), colored in orange. Figure 5.2(e) shows the new solution graph, where the new path divides into two new key-paths. Two of the edges are colored in dark turquoise because they are now used in all three commodity solutions. The solution graph after the application of KPEN can also be seen one-colored in Figure 5.2(f). Algorithm 5.2 shows the KPEN, where we use a Best-Improvement strategy. *bestsolution* is a tuple (P_{old}, P_{new}), which is to be applied to $GSol$ by deleting P_{old} and adding P_{new}.

For the HESND we have to change the algorithm as we only need to delete the edges of commodity solution graphs containing the key-path and not the nodes.

5.1.3 VND

Algorithm 5.3 shows the VND, where N_1 represents the RCN and N_2 represents the KPEN and hence, $k_{max} = 2$.

Algorithm 5.3 VND$(G, Q, GSol)$

Input: A graph G, a set of commodities Q and a solution graph $GSol$
Output: An improved solution

$k := 1$
repeat
  Find a $GSol'$ with $c(GSol') \leq c(GSol'')$, $\forall\ GSol'' \in N_k(GSol)$
  if $c(GSol') < c(GSol)$ **then**
    $GSol := GSol'$
    $k := 1$
  else
    $k := k + 1$
  end if
until $k > k_{max}$
return $GSol$

5.2 Multi-start VND

Now we aim at improving the VND as we do not start from one solution only, but from multiple initial solutions. We therefore make use of the randomization possibility of CH3, as already illustrated in Chapter 4. The number of initial starting solutions is denoted by *nr_initsol*.

The first two starting solutions are given by CH1 and CH2. The rest is given by the randomized CH3, as outlined in Algorithm 5.4.

Algorithm 5.4 works as follows. The order of the commodities is mixed and then the commodities are solved in the order achieved after the mixing. In other words, the order of the commodities is shaken. Apart from that, it works the same as Algorithm 4.5.

Algorithm 5.5 shows the Multi-start VND, as described above. In Chapter 5 we also test this approach with a randomized version of CH4. The randomization works analogous as for the randomized CH3, therefore we spare the details here.

Algorithm 5.4 RandomizedCH3(G, Q)

Input: A graph G and a set of commodities Q
Output: A feasible solution, if there exists one, $\emptyset$ otherwise

if $QuickFeasibilityCheck(G, Q)$ **then**
    Shake the order of the commodities in Q
    for all $q \in Q$ in the order after the shaking **do**
        $G' = \emptyset$
        if $k_q = 1$ **then**
            $G' = SolvingSingleCommodity\_kIsOne(G, q)$
        else
            $G' = SolvingSingleCommodity\_HeuristicX(G, q)$
        end if
        if $G' = \emptyset$ **then**
            return $\emptyset$
        end if
        for all $e \in E_{G'}$ **do**
            Set $c_e = 0$
        end for
        $GSol = GSol \cup G'$
    end for
end if
return $GSol$

Algorithm 5.5 MultiStartVND($G, Q, nr\_initsol$)

Input: A graph G, a set of commodities Q and the number of initial solutions $nr\_initsol$

Output: A feasible improved solution, if a feasible solution is possible

```
if QuickFeasibilityCheck(G, Q) then
   GSol := ConstructiveHeuristic1(G, Q)
   if GSol = ∅ then
      return ∅
   end if
   VND(G, Q, GSol)
   best := c(GSol)
   bestsolution := GSol
   GSol := ConstructiveHeuristic2(G, Q)
   VND(G, Q, GSol)
   if c(GSol) < best then
      best := c(GSol)
      bestsolution := GSol
   end if
   for i := 3 to nr_initsol do
      GSol := RandomizedCH3(G, Q)
      VND(G, Q, GSol)
      if c(GSol) < best then
         best := c(GSol)
         bestsolution := GSol
      end if
   end for
end if
return bestsolution
```

5.3 Greedy randomized adaptive search procedure (GRASP)

In this section, we present a GRASP approach [29, 67, 70]. Instead of a local search we use again our VND. The only greedy constructive heuristic we have is CH1, therefore we randomize this constructive heuristic.

The randomization of CH1 works as follows. Algorithm 5.6 is mostly similar to Algorithm 4.1. The biggest difference is that the edges are not sorted increasingly according to their cost. Algorithm 5.6 also makes use of Algorithm 4.2, which solves the commodities with $k_q = 1$ first. The randomization takes place in Algorithm 5.7, which is the randomized variant of Algorithm 4.3.

Algorithm 5.6 RandomizedCH1(G, Q, α)

Input: A graph G, a set of commodities Q and $\alpha \in [0, 1]$
Output: A feasible solution, if there exists one, $\emptyset$ otherwise

if $QuickFeasibilityCheck(G, Q) \wedge TestFeasibility(G, Q)$ **then**
  $GSol = \emptyset$
  $CH1\_One(G, Q, GSol)$
  $RCH1\_Edge(G, Q, \alpha, GSol)$
  return $GSol$
end if
return $\emptyset$

Algorithm 5.7 RCH1_Edge$(G, Q, \alpha, GSol)$

Input: A graph G, a set of commodities Q and a solution graph $GSol$
Output: $GSol$ augmented by the solution to all commodities where $k_q \neq 1$

for all blocks b which are not yet solved completely **do**
  while b is not marked solved **do**
    Compute RCL for block b
    Choose edge e from RCL randomly
    $GSol = GSol \cup e$
    $DetermineComponents(GSol)$
    $DetermineBlocks(GSol)$
    for all $q \in Q$ with $b \in bl(s_q)$ and q not marked solved **do**
      if $TestFeasibility(GSol, q)$ **then**
        Mark q as solved
        if b has no unsolved commodity left **then**
          Mark b as solved
        end if
      end if
    end for
  end while
end for

So the randomization in Algorithm 5.7 works as follows. We now have a so-called restricted candidate list (RCL). The RCL consists of all edges that are incident to at least one node of the current solution and fulfill the following property, $c_e \leq c_{min} + \alpha \cdot (c_{max} - c_{min})$. c_{min} is the minimum cost value of all remaining edges that are incident to at least one node in the current solution, whereas c_{max} is the maximum cost value of all remaining edges that are incident to at least one node in the current solution, and $\alpha \in [0, 1]$. The RCL is computed for each block separately. Instead of taking the cheapest edge in every iteration, we now choose an edge e from RCL randomly. Hence, the randomization rate is strongly dependent on the value of α. In the next chapter we test the GRASP approach with different values of α.

Algorithm 5.8 shows the composition of all these elements to a GRASP approach. For the tests in Chapter 6, this algorithm is invoked more than once and therefore, due to the randomization, should result in different solutions.

Algorithm 5.8 GRASP(G, Q, α)

Input: A graph G, a set of commodities Q and $\alpha \in [0, 1]$
Output: A feasible (improved) solution, if there exists one

```
if QuickFeasibilityCheck(G, Q) then
    GSol := RandomizedCH1(G, Q, α)
    if GSol = ∅ then
        return ∅
    end if
    VND(G, Q, GSol)
    return GSol
end if
```

Chapter 6

Implementation and computational results

In this chapter, we shortly discuss the implementation and the instance sets. Furthermore, we present result tables for all implemented solution algorithms, as well as results regarding the different feasibility test methods. Comprehensive and detailed result tables can be found in Appendix A. Moreover, the computational results are discussed.

6.1 Implementation

The algorithms presented in this thesis have been implemented in C++. The implementation consists of all algorithms we have developed throughout the thesis. To describe the implementation in detail would go far beyond the scope of this thesis.

6.2 Instances

We tested the implemented algorithms on a big set of instances. For the HESND algorithms, we compare our solution values with the optimal results of Botton [16], regarding the TC-21 and TE-21 instance sets. For the remaining instance sets, there are no comparable results. The same holds for testing the HN-SND algorithms regarding all instance sets. The TC-21 and TE-21 instance sets

Table 6.1: Key data of the "small" instance sets.

	N	$\|V\|$	$\|E\|$	$\|Q\|$
TC-21-5	5	21	210	5
TC-21-10	5	21	210	10
TE-21-5	5	21	210	5
TE-21-10	5	21	210	10
dfn-gwin	1	11	47	55
di-yuan	1	11	42	22
nobel-us	1	14	21	91
pdh	1	11	34	24
polska	1	12	18	66

Table 6.2: Key data of the "big" instance sets.

	$\|V\|$	$\|E\|$	$\|Q\|$
TC-40-5	41	820	5
TC-40-10	41	820	10
TC-60-5	61	1830	5
TC-60-10	61	1830	10
TC-80-5	81	3240	5
TC-80-10	81	3240	10
TE-40-5	41	820	5
TE-40-10	41	820	10
TE-60-5	61	1830	5
TE-60-10	61	1830	10
TE-80-5	81	3240	5
TE-80-10	81	3240	10

were thankfully given to us by Quentin Botton, a description of these instance sets are given in [15]. The other TC and TE instance sets are randomized complete graphs with a self-made randomized set of commodities. The remaining instances were obtained directly from the SNDlib project [64], where also a description of these instances can be found. Tables 6.1 and 6.2 shows the key data of these instance sets, where N denotes the number of instances in this set. We tested all instances with global values for $h_q = 3, 4, 5$ and $k_q = 1, 2, 3$.

As can be seen, the TE and TC instances denote complete graphs with a small number of commodities, whereas the SNDlib instances are sparse graphs with a large set of commodities.

Table 6.3: Feasibility results on "small" instance sets for node-disjointness.

	$QUICK$	ADV	ADV_T	EXT_T	TN	FP
TC	28.340.417	20.535.932	9.273.225	9.101.932	67,28%	1,85%
TE	32.377.773	23.221.353	10.224.919	10.067.917	68,42%	1,54%
SNDlib	29.085.037	15.939.170	8.184.699	8.141.381	71,86%	0,53%
Total	89.803.227	59.696.455	27.682.843	27.311.230	69,17%	1,34%

Table 6.4: Feasibility results on "small" instance sets for edge-disjointness.

	$QUICK$	ADV	ADV_T	EXT_T	TN	FP
TC	27.459.265	22.605.831	9.039.804	8.923.624	67,08%	1,29%
TE	29.445.607	24.819.421	9.189.196	9.088.377	68,79%	1,10%
SNDlib	20.469.621	12.220.672	5.661.281	5.608.819	72,34%	0,92%
Total	77.374.493	59.645.924	23.890.281	23.620.820	69,12%	1,13%

6.3 Computational results

6.3.1 Feasibility test

First we present the computational results regarding the feasibility test, as the development of the feasibility test is one of the main parts of this thesis. As our advanced feasibility test checks against an upper bound, it is of course very interesting to see, how good this upper bound really is in practice. Table 6.3 shows the results for the node-disjointness test runs, Table 6.4 shows the results for the edge-disjointness test runs. $QUICK$ denotes the number of quick checks and ADV denotes the number of advanced checks. ADV_T denotes the number of advanced checks, which evaluated to true, and EXT_T denotes the number of advanced tests, which evaluated to true. $TN = 1 - \frac{ADV_T}{QUICK}$ denotes the number of "true negatives", i.e. the number of tests, where the advanced check evaluated to true in relation to all tests. $FP = 1 - \frac{EXT_T}{ADV_T}$ denotes the number of "false positives", i.e. the number of tests, where the advanced check evaluated to true, but the exact test evaluated to false.

As can be seen in Tables 6.3 and 6.4, the advanced feasibility check yields quite good results in practice, irrespective of whether complete graphs or sparse graphs and whether a big or a small number of commodities.

6.3.2 Results on the "small" instances

Next we present the result tables regarding our different solution algorithms on the instance sets TC-21 and TE-21 as well as the SNDlib instance sets. Tables 6.5 to 6.8 show the average results on all test sets for the node disjointness solution algorithms, whereas Tables 6.9 to 6.12 show the average results on all test sets for the edge disjointness solution algorithms, where we additionally present the results of Botton (abbreviated by *BOT*) for comparison reasons. The tables show the mean objective value of all five instances regarding one combination of limits.

To save space we omitted the "H" in all abbreviations, e.g. CH1 is in the tables abbreviated with C1. As a short reminder, SH1 is the single-commodity solution algorithm, which is a modification of the exact feasibility test, SH2 is the greedy algorithm and SH3F the algorithm, which makes use of the shortest-hop-constrained-path algorithm including the fallback. Moreover, CH1 is the greedy constructive heuristic, CH2 the divide-and-conquer approach, CH3 the modified CH2, where the edge costs of used edges is set to zero before solving the next commoditiy, and in CH4 we first try to solve the commodities with SH3. Comprehensive and detailed result tables can be found in Appendix A.

For all instance names we added information about the global limits, i.e. the second last number denotes h_q of all commodities and the last number denotes k_q of all commodities, e.g. TC-21-5-3-2 means that in this instance set $h_q = 3$ and $k_q = 2$ for all commodities. For comparison reasons we tested only global commodity limits. This does not change the fact, that all developed and implemented algorithms are able to deal with different commodity limits too. The computations were performed on a single core of an Intel Xeon E5540 processor with 2.53 GHz and 3GB RAM, with a time limit of 3600 seconds. As can be seen in Appendix A, the time consumation on these instance sets is mostly less than one second, only in some cases a couple of seconds. For the MSVND and the GRASP tests we performed 30 runs for each instance, in order to compute μ (mean) and σ (standard deviation).

Regarding node disjointness, among constructive heuristics, CH3 and CH4 yield the best objective values, when $k_q = 1$, as can be seen from Table 6.5. If $k_q > 1$, then CH1 seems to perform best on average. This observation also holds for the SNDlib instances, as can be seen in Table A.33.

If the constructive heuristics are followed by the VND, one can observe from Table 6.6 that this previous mentioned partitioning does not hold any more. Here, CH2 with SH3F performs best on average if followed by a VND. Furthermore, the objective values have improved for each approach. As can be seen from Table A.35, VND with CH1 performs best on average regarding sparse graphs.

Regarding node disjointness, the MSVND produces slightly better results with RCH4, the randomized CH4, than using RCH3. But as Table 6.7 shows, the results are on the average not far apart from each other. This also holds for the SNDlib instances, as can be seen in Table A.37.

The GRASP approach yields the best results with $\alpha = 0.0$ and $\alpha = 0.2$. Note that even for $\alpha = 0.0$ different solutions can be reached, since there can be edges with the same costs. The randomized CH1 now chooses one of these edges randomly, whereas CH1 takes always the next edge in the sorted list. This result also holds for the SNDlib instances, as can be seen in Table A.39. If all commodities have $k_q = 1$ the result is the same for all α, as only the shortest-hop-constrained-path algorithm is invoked.

Table 6.5: Average results over five instances (node disjointness), regarding constructive heuristics.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TC-21-5-3-1	198.8	198.8	198.8	198.8	**154.6**	**154.6**	**154.6**	**154.6**	**154.6**	**154.6**
TC-21-5-3-2	**315.8**	503.4	390.0	379.8	503.4	366.2	325.4	325.4	325.4	325.4
TC-21-5-3-3	**498.6**	797.2	616.0	580.2	797.2	548.2	523.4	523.4	523.4	523.4
TC-21-5-4-1	198.8	198.8	198.8	198.8	**154.6**	**154.6**	**154.6**	**154.6**	**154.6**	**154.6**
TC-21-5-4-2	348.2	503.4	405.4	379.8	503.4	387.0	**325.4**	**325.4**	**325.4**	**325.4**
TC-21-5-4-3	**500.2**	797.2	622.2	580.2	797.2	546.8	523.4	523.4	523.4	523.4
TC-21-5-5-1	198.8	198.8	198.8	198.8	**154.6**	**154.6**	**154.6**	**154.6**	**154.6**	**154.6**
TC-21-5-5-2	325.8	503.4	385.4	379.8	503.4	362.6	**325.4**	**325.4**	**325.4**	**325.4**
TC-21-5-5-3	**471.8**	797.2	623.0	580.2	797.2	547.6	523.4	523.4	523.4	523.4
TC-21-10-3-1	405.8	405.8	405.8	405.8	**264.4**	**264.4**	**264.4**	**264.4**	**264.4**	**264.4**
TC-21-10-3-2	**525.4**	965.4	663.0	726.8	965.4	594.8	556.0	556.0	556.0	556.0
TC-21-10-3-3	**792.8**	1488.2	979.0	1040.2	1488.2	848.0	860.6	860.6	860.6	860.6
TC-21-10-4-1	405.8	405.8	405.8	405.8	**264.4**	**264.4**	**264.4**	**264.4**	**264.4**	**264.4**
TC-21-10-4-2	**492.0**	965.4	593.4	726.8	965.4	534.0	556.0	556.0	556.0	556.0
TC-21-10-4-3	**693.2**	1488.2	941.8	1040.2	1488.2	783.6	860.6	860.6	860.6	860.6
TC-21-10-5-1	405.8	405.8	405.8	405.8	**264.4**	**264.4**	**264.4**	**264.4**	**264.4**	**264.4**
TC-21-10-5-2	**469.6**	965.4	579.0	726.8	965.4	507.6	556.0	556.0	556.0	556.0
TC-21-10-5-3	**654.4**	1488.2	891.6	1040.2	1488.2	745.8	860.6	860.6	860.6	860.6
TE-21-5-3-1	351.6	351.6	351.6	351.6	**224.4**	**224.4**	**224.4**	**224.4**	**224.4**	**224.4**
TE-21-5-3-2	**450.0**	684.6	546.4	635.2	684.6	491.8	464.6	464.6	464.6	464.6
TE-21-5-3-3	**673.0**	1073.8	797.6	920.6	1073.8	738.6	695.2	695.2	695.2	695.2
TE-21-5-4-1	351.6	351.6	351.6	351.6	**224.4**	**224.4**	**224.4**	**224.4**	**224.4**	**224.4**
TE-21-5-4-2	**423.4**	684.6	476.0	635.2	684.6	441.0	462.2	462.2	462.2	462.2
TE-21-5-4-3	**653.0**	1073.8	788.0	920.6	1073.8	697.4	692.8	692.8	692.8	692.8
TE-21-5-5-1	351.6	351.6	351.6	351.6	**224.4**	**224.4**	**224.4**	**224.4**	**224.4**	**224.4**
TE-21-5-5-2	**435.4**	684.6	501.2	635.2	684.6	464.2	462.2	462.2	462.2	462.2
TE-21-5-5-3	**626.2**	1073.8	740.2	920.6	1073.8	643.0	692.8	692.8	692.8	692.8
TE-21-10-3-1	674.4	674.4	674.4	674.4	**348.2**	**348.2**	**348.2**	**348.2**	**348.2**	**348.2**
TE-21-10-3-2	**682.4**	1239.0	912.4	1164.6	1239.0	801.6	728.2	728.2	728.2	728.2
TE-21-10-3-3	**950.8**	1805.4	1309.4	1615.2	1805.4	1150.6	1125.8	1125.8	1125.8	1125.8
TE-21-10-4-1	674.4	674.4	674.4	674.4	**317.2**	**317.2**	**317.2**	**317.2**	**317.2**	**317.2**
TE-21-10-4-2	**578.0**	1239.0	788.4	1164.6	1239.0	655.4	716.4	716.4	716.4	716.4
TE-21-10-4-3	**830.0**	1805.4	1157.2	1615.2	1805.4	975.2	1122.2	1122.2	1122.2	1122.2
TE-21-10-5-1	674.4	674.4	674.4	674.4	**312.6**	**312.6**	**312.6**	**312.6**	**312.6**	**312.6**
TE-21-10-5-2	**526.0**	1239.0	679.0	1164.6	1239.0	604.0	720.2	720.2	720.2	720.2
TE-21-10-5-3	**780.4**	1805.4	1041.4	1615.2	1805.4	875.4	1122.2	1122.2	1122.2	1122.2

Table 6.6: Average results over five instances (node disjointness), regarding VND.

	VND with									
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TC-21-5-3-1	145.8	145.8	145.8	145.8	**144.4**	**144.4**	**144.4**	**144.4**	**144.4**	**144.4**
TC-21-5-3-2	271.2	255.6	284.4	255.0	255.6	289.0	**249.8**	**249.8**	**249.8**	**249.8**
TC-21-5-3-3	441.4	438.0	449.2	420.0	438.0	451.4	**423.4**	**423.4**	**423.4**	**423.4**
TC-21-5-4-1	145.8	145.8	145.8	145.8	**144.4**	**144.4**	**144.4**	**144.4**	**144.4**	**144.4**
TC-21-5-4-2	284.6	**244.6**	277.4	249.8	**244.6**	292.8	249.8	249.8	249.8	249.8
TC-21-5-4-3	447.2	438.0	425.4	**420.0**	438.0	465.8	423.4	423.4	423.4	423.4
TC-21-5-5-1	145.8	145.8	145.8	145.8	**144.4**	**144.4**	**144.4**	**144.4**	**144.4**	**144.4**
TC-21-5-5-2	292.4	**244.6**	261.6	249.8	**244.6**	291.2	249.8	249.8	249.8	249.8
TC-21-5-5-3	433.4	438.0	425.0	**420.0**	438.0	438.0	423.4	423.4	423.4	423.4
TC-21-10-3-1	**235.0**	**235.0**	**235.0**	**235.0**	236.4	236.4	236.4	236.4	236.4	236.4
TC-21-10-3-2	504.4	**449.0**	497.6	449.8	**449.0**	512.4	455.0	455.0	455.0	455.0
TC-21-10-3-3	744.2	689.8	740.8	679.6	689.8	747.6	**673.0**	**673.0**	**673.0**	**673.0**
TC-21-10-4-1	**236.2**	**236.2**	**236.2**	**236.2**	236.4	236.4	236.4	236.4	236.4	236.4
TC-21-10-4-2	456.4	421.0	464.8	418.0	421.0	471.6	**415.2**	**415.2**	**415.2**	**415.2**
TC-21-10-4-3	670.4	676.2	691.8	663.8	676.2	690.6	**649.8**	**649.8**	**649.8**	**649.8**
TC-21-10-5-1	**236.2**	**236.2**	**236.2**	**236.2**	236.4	236.4	236.4	236.4	236.4	236.4
TC-21-10-5-2	411.8	402.8	414.8	412.4	402.8	429.0	**401.6**	**401.6**	**401.6**	**401.6**
TC-21-10-5-3	**610.2**	663.8	626.6	659.8	663.8	668.0	647.6	647.6	647.6	647.6
TE-21-5-3-1	**193.8**	**193.8**	**193.8**	**193.8**	198.8	198.8	198.8	198.8	198.8	198.8
TE-21-5-3-2	396.4	380.4	419.6	**370.0**	380.4	425.6	390.2	390.2	390.2	390.2
TE-21-5-3-3	616.2	573.6	617.6	**526.4**	573.6	634.6	569.4	569.4	569.4	569.4
TE-21-5-4-1	**193.8**	**193.8**	**193.8**	**193.8**	198.8	198.8	198.8	198.8	198.8	198.8
TE-21-5-4-2	394.0	360.2	392.8	**345.4**	360.2	384.2	359.4	359.4	359.4	359.4
TE-21-5-4-3	580.6	532.8	556.6	**513.2**	532.8	557.2	527.0	527.0	527.0	527.0
TE-21-5-5-1	**193.8**	**193.8**	**193.8**	**193.8**	198.8	198.8	198.8	198.8	198.8	198.8
TE-21-5-5-2	357.8	351.6	365.0	**332.6**	351.6	367.8	340.2	340.2	340.2	340.2
TE-21-5-5-3	536.8	532.6	533.0	**512.8**	532.6	533.4	527.0	527.0	527.0	527.0
TE-21-10-3-1	**258.6**	**258.6**	**258.6**	**258.6**	284.2	284.2	284.2	284.2	284.2	284.2
TE-21-10-3-2	674.4	564.6	691.0	**552.0**	564.6	705.0	610.4	610.4	610.4	610.4
TE-21-10-3-3	946.8	848.6	997.6	**830.0**	848.6	987.0	902.0	902.0	902.0	902.0
TE-21-10-4-1	**258.6**	**258.6**	**258.6**	**258.6**	282.2	282.2	282.2	282.2	282.2	282.2
TE-21-10-4-2	570.0	505.6	589.4	**496.4**	505.6	591.0	530.8	530.8	530.8	530.8
TE-21-10-4-3	812.8	755.0	917.0	**740.4**	755.0	852.8	810.6	810.6	810.6	810.6
TE-21-10-5-1	**258.6**	**258.6**	**258.6**	**258.6**	283.4	283.4	283.4	283.4	283.4	283.4
TE-21-10-5-2	499.4	479.6	523.4	**470.0**	479.6	511.2	495.0	495.0	495.0	495.0
TE-21-10-5-3	766.8	725.8	785.0	**719.8**	725.8	793.0	748.8	748.8	748.8	748.8

Table 6.7: Average results over five instances (node disjointness), regarding MSVND.

	MSVND with											
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TC-21-5-3-1	141.09	0.95	141.05	0.82	141.05	0.82	141.15	0.89	**140.98**	0.74	141.01	0.78
TC-21-5-3-2	255.60	0.00	255.60	0.00	255.60	0.00	242.85	0.29	**242.80**	0.00	242.95	0.80
TC-21-5-3-3	438.00	0.00	438.00	0.00	438.00	0.00	407.07	2.98	406.77	1.37	**406.21**	1.35
TC-21-5-4-1	141.00	0.56	**140.93**	0.35	141.05	0.82	141.03	0.43	140.98	0.74	141.07	0.45
TC-21-5-4-2	244.60	0.00	244.60	0.00	244.60	0.00	**242.80**	0.00	**242.80**	0.00	**242.80**	0.00
TC-21-5-4-3	438.00	0.00	438.00	0.00	438.00	0.00	**405.76**	4.67	405.97	3.04	406.10	3.78
TC-21-5-5-1	141.16	1.02	**140.93**	0.35	141.05	0.82	141.13	1.14	141.09	0.62	140.97	0.38
TC-21-5-5-2	244.60	0.00	244.60	0.00	244.60	0.00	**242.80**	0.00	242.80	0.00	242.80	0.00
TC-21-5-5-3	438.00	0.00	438.00	0.00	438.00	0.00	405.84	3.87	**405.82**	3.09	406.19	4.13
TC-21-10-3-1	226.28	4.41	225.85	4.68	**225.33**	4.31	226.48	4.07	226.33	4.01	225.94	4.11
TC-21-10-3-2	449.00	0.00	449.00	0.00	449.00	0.00	**430.55**	8.08	431.07	8.35	430.77	8.71
TC-21-10-3-3	689.80	0.00	689.80	0.00	689.80	0.00	643.77	13.04	641.83	12.66	**641.37**	11.40
TC-21-10-4-1	228.23	3.94	227.01	3.84	**226.45**	3.36	227.63	4.14	227.18	3.53	227.27	4.00
TC-21-10-4-2	421.00	0.00	421.00	0.00	421.00	0.00	**395.97**	6.75	396.45	6.91	396.65	6.82
TC-21-10-4-3	676.20	0.00	676.20	0.00	676.20	0.00	615.96	14.95	615.53	13.77	**615.06**	14.48
TC-21-10-5-1	**226.63**	3.95	226.81	3.32	227.69	3.77	226.99	3.36	226.89	3.59	226.87	3.98
TC-21-10-5-2	402.80	0.00	402.80	0.00	402.80	0.00	**376.88**	9.38	377.35	9.02	378.10	7.76
TC-21-10-5-3	663.80	0.00	663.80	0.00	663.80	0.00	**610.55**	13.42	611.65	13.14	612.33	12.06
TE-21-5-3-1	188.19	1.61	**187.72**	0.88	187.92	1.20	188.06	1.24	187.93	1.25	188.17	1.84
TE-21-5-3-2	380.40	0.00	380.40	0.00	380.40	0.00	362.96	10.26	**362.08**	10.20	363.79	9.94
TE-21-5-3-3	573.60	0.00	573.60	0.00	573.60	0.00	529.51	13.55	531.37	13.86	**529.13**	14.05
TE-21-5-4-1	187.95	1.46	187.81	0.62	187.81	0.79	188.03	1.09	187.89	0.95	**187.69**	0.49
TE-21-5-4-2	360.20	0.00	360.20	0.00	360.20	0.00	332.62	8.12	332.93	9.60	**332.35**	7.88
TE-21-5-4-3	532.80	0.00	532.80	0.00	532.80	0.00	495.95	15.93	**494.17**	15.44	497.71	16.13
TE-21-5-5-1	188.12	1.13	188.03	0.97	188.04	1.02	187.64	0.65	**187.86**	1.05	187.81	0.82
TE-21-5-5-2	351.60	0.00	351.60	0.00	351.60	0.00	302.17	11.89	302.17	12.49	**302.15**	13.00
TE-21-5-5-3	532.60	0.00	532.60	0.00	532.60	0.00	488.95	14.15	490.01	16.01	**485.54**	14.89
TE-21-10-3-1	254.23	5.52	254.05	5.31	253.89	5.49	**253.36**	5.18	253.69	5.38	253.63	5.28
TE-21-10-3-2	564.60	0.00	564.60	0.00	564.60	0.00	551.99	16.73	**551.01**	16.74	552.95	16.47
TE-21-10-3-3	848.60	0.00	848.60	0.00	848.60	0.00	**819.49**	23.03	821.76	23.78	822.87	24.10
TE-21-10-4-1	**252.58**	6.19	253.60	5.88	252.97	6.06	253.13	5.99	253.23	5.73	253.56	6.47
TE-21-10-4-2	505.60	0.00	505.60	0.00	505.60	0.00	**489.81**	13.83	490.77	13.13	490.77	14.21
TE-21-10-4-3	755.00	0.00	755.00	0.00	755.00	0.00	716.54	24.86	**716.52**	26.59	718.63	25.19
TE-21-10-5-1	252.71	6.70	253.43	6.39	253.43	5.89	**252.53**	5.07	253.13	5.96	253.15	5.76
TE-21-10-5-2	479.60	0.00	479.60	0.00	479.60	0.00	453.26	13.29	452.47	15.24	**451.42**	11.36
TE-21-10-5-3	725.80	0.00	725.80	0.00	725.80	0.00	679.55	21.59	677.09	24.46	**675.81**	21.34

Table 6.8: Average results over five instances (node disjointness), regarding GRASP.

	GRASP											
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TC-21-5-3-1	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00
TC-21-5-3-2	**273.07**	2.36	277.83	21.05	280.69	28.54	298.25	48.34	312.31	51.07	324.93	61.60
TC-21-5-3-3	445.05	13.66	**441.15**	28.43	449.75	37.46	454.75	43.23	470.74	58.41	486.73	64.69
TC-21-5-4-1	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00
TC-21-5-4-2	279.69	7.33	**266.47**	26.69	280.33	31.05	309.01	51.68	325.18	65.55	328.80	61.30
TC-21-5-4-3	**431.10**	12.59	434.34	27.58	445.63	36.30	474.67	55.41	492.89	78.24	496.75	75.15
TC-21-5-5-1	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00
TC-21-5-5-2	288.93	10.72	**271.16**	26.55	274.35	30.86	302.92	54.15	307.53	61.99	319.81	72.13
TC-21-5-5-3	430.12	16.35	**428.60**	29.41	442.26	41.39	482.82	70.23	493.39	75.72	501.42	74.44
TC-21-10-3-1	**235.00**	0.00	**235.00**	0.00	**235.00**	0.00	**235.00**	0.00	**235.00**	0.00	**235.00**	0.00
TC-21-10-3-2	**493.01**	11.51	494.83	25.86	526.95	41.32	588.93	61.69	641.79	84.28	644.30	79.65
TC-21-10-3-3	**725.86**	22.64	734.42	43.24	770.79	55.99	863.87	85.21	932.54	91.33	962.79	106.67
TC-21-10-4-1	**236.20**	0.00	**236.20**	0.00	**236.20**	0.00	**236.20**	0.00	**236.20**	0.00	**236.20**	0.00
TC-21-10-4-2	**455.55**	11.77	460.53	26.15	521.68	50.76	605.51	76.36	664.29	92.12	696.32	95.73
TC-21-10-4-3	**658.45**	11.62	680.26	36.82	759.89	65.14	874.21	85.91	967.29	114.70	999.10	129.09
TC-21-10-5-1	**236.20**	0.00	**236.20**	0.00	**236.20**	0.00	**236.20**	0.00	**236.20**	0.00	**236.20**	0.00
TC-21-10-5-2	**408.85**	15.46	435.11	30.52	510.97	56.51	589.75	73.75	655.37	99.02	688.89	106.91
TC-21-10-5-3	**615.12**	5.55	655.30	36.00	750.84	63.27	880.61	92.65	961.70	109.45	1000.93	135.77
TE-21-5-3-1	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00
TE-21-5-3-2	**405.87**	13.37	410.50	20.93	415.46	23.60	426.20	39.57	455.77	58.70	452.07	65.67
TE-21-5-3-3	**624.84**	9.78	626.77	27.94	631.57	28.78	617.39	50.08	637.86	68.29	644.59	71.38
TE-21-5-4-1	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00
TE-21-5-4-2	**386.66**	10.06	388.67	19.65	391.77	35.19	405.16	50.39	423.51	60.24	426.04	61.04
TE-21-5-4-3	580.93	13.56	**576.22**	35.30	586.51	51.22	603.57	60.24	613.66	80.84	613.97	73.87
TE-21-5-5-1	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00
TE-21-5-5-2	**360.55**	5.33	365.60	27.07	374.66	43.75	381.22	55.01	399.13	72.79	408.26	76.39
TE-21-5-5-3	565.44	19.65	554.48	41.49	**552.54**	44.36	582.35	60.44	600.85	72.63	606.05	75.82
TE-21-10-3-1	**258.60**	0.00	**258.60**	0.00	**258.60**	0.00	**258.60**	0.00	**258.60**	0.00	**258.60**	0.00
TE-21-10-3-2	653.02	18.92	**647.65**	32.61	653.70	35.28	681.26	57.75	740.87	78.09	749.30	85.35
TE-21-10-3-3	953.60	19.94	**952.70**	36.23	966.54	48.32	993.78	58.90	1058.53	97.53	1092.08	109.18
TE-21-10-4-1	**258.60**	0.00	**258.60**	0.00	**258.60**	0.00	**258.60**	0.00	**258.60**	0.00	**258.60**	0.00
TE-21-10-4-2	**553.28**	25.01	563.79	32.25	601.00	48.09	676.16	74.50	729.55	96.69	756.58	98.90
TE-21-10-4-3	**816.06**	27.67	834.04	39.13	873.93	58.35	978.44	86.05	1064.14	116.04	1088.64	119.58
TE-21-10-5-1	**258.60**	0.00	**258.60**	0.00	**258.60**	0.00	**258.60**	0.00	**258.60**	0.00	**258.60**	0.00
TE-21-10-5-2	**491.40**	10.09	521.96	29.01	577.09	52.35	673.15	85.50	733.47	101.28	737.04	106.06
TE-21-10-5-3	**757.81**	18.85	773.62	40.60	841.45	68.36	972.95	108.30	1048.25	116.75	1068.15	138.15

Table 6.9: Average results over five instances (edge disjointness), regarding constructive heuristics.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F	**BOT**
TC-21-5-3-1	198.8	198.8	198.8	198.8	**154.6**	**154.6**	**154.6**	**154.6**	**154.6**	**154.6**	**140.2**
TC-21-5-3-2	**318.8**	802.0	409.0	379.8	802.0	378.8	**325.4**	**325.4**	**325.4**	**325.4**	**237.8**
TC-21-5-3-3	525.2	1086.6	616.8	580.2	1086.6	570.2	**523.4**	**523.4**	**523.4**	**523.4**	**376.0**
TC-21-5-4-1	198.8	198.8	198.8	198.8	**154.6**	**154.6**	**154.6**	**154.6**	**154.6**	**154.6**	**140.2**
TC-21-5-4-2	341.0	933.4	416.0	379.8	933.4	373.4	**307.2**	**307.2**	**307.2**	**307.2**	**237.8**
TC-21-5-4-3	**476.6**	1170.6	623.2	580.2	1170.6	512.2	488.8	488.8	488.8	488.8	**369.8**
TC-21-5-5-1	198.8	198.8	198.8	198.8	**154.6**	**154.6**	**154.6**	**154.6**	**154.6**	**154.6**	**140.2**
TC-21-5-5-2	334.0	927.8	392.6	379.8	927.8	358.0	**307.2**	**307.2**	**307.2**	**307.2**	**222.6**
TC-21-5-5-3	507.8	1244.6	612.4	580.2	1244.6	545.0	**486.6**	**486.6**	**486.6**	**486.6**	**369.8**
TC-21-10-3-1	405.8	405.8	405.8	405.8	**264.4**	**264.4**	**264.4**	**264.4**	**264.4**	**264.4**	**233.0**
TC-21-10-3-2	**527.6**	1504.8	650.0	726.8	1504.8	581.6	553.4	553.4	553.4	553.4	**401.4**
TC-21-10-3-3	**788.2**	2026.4	919.0	1040.2	2026.4	850.4	856.8	856.8	856.8	856.8	**577.2**
TC-21-10-4-1	405.8	405.8	405.8	405.8	**264.4**	**264.4**	**264.4**	**264.4**	**264.4**	**264.4**	**223.4**
TC-21-10-4-2	**495.2**	1619.2	599.8	726.8	1619.2	531.4	521.0	521.0	521.0	521.0	**362.6**
TC-21-10-4-3	**688.2**	2100.2	887.0	1040.2	2100.2	785.2	785.4	785.4	785.4	785.4	**544.2**
TC-21-10-5-1	405.8	405.8	405.8	405.8	**264.4**	**264.4**	**264.4**	**264.4**	**264.4**	**264.4**	**222.6**
TC-21-10-5-2	**462.4**	1603.4	543.4	726.8	1603.4	502.2	520.0	520.0	520.0	520.0	**347.6**
TC-21-10-5-3	**689.8**	2140.6	799.8	1040.2	2140.6	738.0	759.6	759.6	759.6	759.6	**530.6**
TE-21-5-3-1	351.6	351.6	351.6	351.6	**224.4**	**224.4**	**224.4**	**224.4**	**224.4**	**224.4**	**191.4**
TE-21-5-3-2	**444.8**	1117.4	546.6	635.2	1117.4	507.6	458.0	458.0	458.0	458.0	**330.6**
TE-21-5-3-3	**660.6**	1437.0	804.8	920.6	1437.0	739.0	688.6	688.6	688.6	688.6	**460.0**
TE-21-5-4-1	351.6	351.6	351.6	351.6	**224.4**	**224.4**	**224.4**	**224.4**	**224.4**	**224.4**	**185.8**
TE-21-5-4-2	**406.8**	1144.2	479.8	635.2	1144.2	430.8	436.6	436.6	436.6	436.6	**306.0**
TE-21-5-4-3	**637.6**	1528.8	764.4	920.6	1528.8	682.0	663.0	663.0	663.0	663.0	**459.2**
TE-21-5-5-1	351.6	351.6	351.6	351.6	**224.4**	**224.4**	**224.4**	**224.4**	**224.4**	**224.4**	**185.6**
TE-21-5-5-2	**417.4**	1259.6	473.4	635.2	1259.6	451.4	436.4	436.4	436.4	436.4	**274.8**
TE-21-5-5-3	**608.0**	1715.8	698.2	920.6	1715.8	656.8	660.2	660.2	660.2	660.2	**457.6**
TE-21-10-3-1	674.4	674.4	674.4	674.4	**348.2**	**348.2**	**348.2**	**348.2**	**348.2**	**348.2**	**281.2**
TE-21-10-3-2	**676.8**	1829.2	922.4	1164.6	1829.2	801.8	721.6	721.6	721.6	721.6	**497.4**
TE-21-10-3-3	**970.8**	2274.0	1304.0	1615.2	2274.0	1091.6	1109.6	1109.6	1109.6	1109.6	**701.0**
TE-21-10-4-1	674.4	674.4	674.4	674.4	**317.2**	**317.2**	**317.2**	**317.2**	**317.2**	**317.2**	**261.2**
TE-21-10-4-2	**581.6**	1805.6	762.8	1164.6	1805.6	631.8	651.8	651.8	651.8	651.8	**433.0**
TE-21-10-4-3	**820.2**	2299.0	1066.2	1615.2	2299.0	935.8	976.8	976.8	976.8	976.8	**615.6**
TE-21-10-5-1	674.4	674.4	674.4	674.4	**312.6**	**312.6**	**312.6**	**312.6**	**312.6**	**312.6**	**250.6**
TE-21-10-5-2	**549.8**	1886.2	655.8	1164.6	1886.2	599.0	626.2	626.2	626.2	626.2	**398.6**
TE-21-10-5-3	**776.6**	2482.4	933.4	1615.2	2482.4	848.6	942.8	942.8	942.8	942.8	**577.2**

Table 6.10: Average results over five instances (edge disjointness), regarding VND.

	VND with										
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F	**BOT**
TC-21-5-3-1	145.8	145.8	145.8	145.8	**144.4**	**144.4**	**144.4**	**144.4**	**144.4**	**144.4**	**140.2**
TC-21-5-3-2	275.4	264.4	283.4	**255.0**	264.4	275.4	249.8	249.8	249.8	249.8	**237.8**
TC-21-5-3-3	427.0	**415.6**	433.4	420.0	**415.6**	442.8	420.0	420.0	420.0	420.0	**376.0**
TC-21-5-4-1	145.8	145.8	145.8	145.8	**144.4**	**144.4**	**144.4**	**144.4**	**144.4**	**144.4**	**140.2**
TC-21-5-4-2	305.2	**270.8**	307.8	273.4	**270.8**	309.2	274.2	274.2	274.2	274.2	**237.8**
TC-21-5-4-3	441.4	488.0	459.0	**425.2**	488.0	447.0	431.4	431.4	431.4	431.4	**369.8**
TC-21-5-5-1	145.8	145.8	145.8	145.8	**144.4**	**144.4**	**144.4**	**144.4**	**144.4**	**144.4**	**140.2**
TC-21-5-5-2	290.4	283.6	304.8	**263.6**	283.6	293.2	270.6	270.6	270.6	270.6	**222.6**
TC-21-5-5-3	462.4	457.4	449.2	**425.2**	457.4	463.0	432.8	432.8	432.8	432.8	**369.8**
TC-21-10-3-1	**244.4**	**244.4**	**244.4**	**244.4**	247.2	247.2	247.2	247.2	247.2	247.2	**233.0**
TC-21-10-3-2	511.8	619.0	511.0	**449.8**	619.0	508.0	463.0	463.0	463.0	463.0	**401.4**
TC-21-10-3-3	755.0	757.2	778.8	678.6	757.2	789.8	**676.0**	**676.0**	**676.0**	**676.0**	**577.2**
TC-21-10-4-1	**238.0**	**238.0**	**238.0**	**238.0**	239.8	239.8	239.8	239.8	239.8	239.8	**223.4**
TC-21-10-4-2	457.2	504.6	508.8	**428.8**	504.6	477.2	446.6	446.6	446.6	446.6	**362.6**
TC-21-10-4-3	**654.8**	770.0	711.6	672.6	770.0	680.6	739.0	739.0	739.0	739.0	**544.2**
TC-21-10-5-1	**236.2**	**236.2**	**236.2**	**236.2**	236.4	236.4	236.4	236.4	236.4	236.4	**222.6**
TC-21-10-5-2	438.6	622.4	482.4	**425.2**	622.4	456.0	440.8	440.8	440.8	440.8	**347.6**
TC-21-10-5-3	659.0	727.0	**640.2**	652.8	727.0	681.2	699.4	699.4	699.4	699.4	**530.6**
TE-21-5-3-1	**203.2**	**203.2**	**203.2**	**203.2**	215.4	215.4	215.4	215.4	215.4	215.4	**191.4**
TE-21-5-3-2	403.6	394.8	406.0	**370.0**	394.8	412.6	408.8	408.8	408.8	408.8	**330.6**
TE-21-5-3-3	622.0	600.0	633.8	**534.0**	600.0	645.0	597.0	597.0	597.0	597.0	**460.0**
TE-21-5-4-1	**193.8**	**193.8**	**193.8**	**193.8**	198.8	198.8	198.8	198.8	198.8	198.8	**185.8**
TE-21-5-4-2	375.6	450.8	383.2	**361.6**	450.8	396.0	412.4	412.4	412.4	412.4	**306.0**
TE-21-5-4-3	574.0	601.8	586.8	**555.0**	601.8	579.4	574.4	574.4	574.4	574.4	**459.2**
TE-21-5-5-1	**193.8**	**193.8**	**193.8**	**193.8**	198.8	198.8	198.8	198.8	198.8	198.8	**185.6**
TE-21-5-5-2	361.4	374.0	363.8	**347.0**	374.0	374.0	390.8	390.8	390.8	390.8	**274.8**
TE-21-5-5-3	568.8	609.6	590.8	555.0	609.6	579.2	**551.8**	**551.8**	**551.8**	**551.8**	**457.6**
TE-21-10-3-1	**314.4**	**314.4**	**314.4**	**314.4**	336.4	336.4	336.4	336.4	336.4	336.4	**281.2**
TE-21-10-3-2	671.6	666.8	701.8	**552.0**	666.8	708.0	615.8	615.8	615.8	615.8	**497.4**
TE-21-10-3-3	954.2	1007.0	980.0	**833.4**	1007.0	969.6	902.0	902.0	902.0	902.0	**701.0**
TE-21-10-4-1	**273.4**	**273.4**	**273.4**	**273.4**	300.8	300.8	300.8	300.8	300.8	300.8	**261.2**
TE-21-10-4-2	568.8	591.0	610.4	**523.4**	591.0	588.4	561.2	561.2	561.2	561.2	**433.0**
TE-21-10-4-3	801.8	901.0	910.4	**766.8**	901.0	857.8	858.6	858.6	858.6	858.6	**615.6**
TE-21-10-5-1	**264.8**	**264.8**	**264.8**	**264.8**	289.0	289.0	289.0	289.0	289.0	289.0	**250.6**
TE-21-10-5-2	530.0	631.0	556.0	**490.0**	631.0	538.0	521.2	521.2	521.2	521.2	**398.6**
TE-21-10-5-3	757.8	848.4	799.4	**753.8**	848.4	782.4	777.8	777.8	777.8	777.8	**577.2**

Table 6.11: Average results over five instances (edge disjointness), regarding MSVND.

	MSVND with												
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F		
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	**BOT**
TC-21-5-3-1	**140.95**	0.69	140.97	0.38	141.08	0.85	141.13	0.99	141.19	1.46	141.00	0.41	**140.20**
TC-21-5-3-2	264.40	0.00	264.40	0.00	264.40	0.00	242.95	0.80	242.85	0.29	**242.80**	0.00	**237.80**
TC-21-5-3-3	415.60	0.00	415.60	0.00	415.60	0.00	**405.27**	5.07	405.83	4.42	405.28	4.39	**376.00**
TC-21-5-4-1	141.03	0.43	141.01	0.78	141.13	0.48	141.00	0.41	**140.97**	0.38	**140.97**	0.38	**140.20**
TC-21-5-4-2	270.80	0.00	270.80	0.00	270.80	0.00	252.79	3.55	253.32	5.79	**252.72**	4.67	**237.80**
TC-21-5-4-3	488.00	0.00	488.00	0.00	488.00	0.00	**404.30**	5.50	408.63	5.80	409.25	5.80	**369.80**
TC-21-5-5-1	141.24	1.08	141.13	0.99	**140.93**	0.35	141.03	0.86	141.05	0.82	141.13	0.99	**140.20**
TC-21-5-5-2	283.60	0.00	283.60	0.00	283.60	0.00	254.35	5.05	254.13	4.10	**254.03**	4.68	**222.60**
TC-21-5-5-3	457.40	0.00	457.40	0.00	457.40	0.00	411.31	4.83	411.91	5.48	**410.62**	4.76	**369.80**
TC-21-10-3-1	238.28	3.62	**237.34**	3.31	237.85	3.51	237.46	3.86	237.53	3.79	237.56	3.49	**233.00**
TC-21-10-3-2	619.00	0.00	619.00	0.00	619.00	0.00	434.11	9.92	432.86	8.09	**431.11**	7.04	**401.40**
TC-21-10-3-3	757.20	0.00	757.20	0.00	757.20	0.00	646.97	13.81	**645.67**	13.39	649.16	12.08	**577.20**
TC-21-10-4-1	229.30	4.37	**228.74**	4.05	228.80	4.06	229.04	4.07	228.90	3.74	229.01	4.03	**223.40**
TC-21-10-4-2	504.60	0.00	504.60	0.00	504.60	0.00	419.15	13.09	**418.83**	14.56	420.25	13.84	**362.60**
TC-21-10-4-3	770.00	0.00	770.00	0.00	770.00	0.00	**643.61**	18.71	644.82	16.55	646.07	17.53	**544.20**
TC-21-10-5-1	227.88	3.19	227.92	3.34	227.88	3.33	**227.65**	2.92	227.85	3.44	228.12	3.30	**222.60**
TC-21-10-5-2	622.40	0.00	622.40	0.00	622.40	0.00	**396.79**	14.30	399.65	12.77	397.23	15.02	**347.60**
TC-21-10-5-3	727.00	0.00	727.00	0.00	727.00	0.00	628.64	18.00	626.85	18.81	**626.14**	17.53	**530.60**
TE-21-5-3-1	**192.89**	2.08	193.99	4.02	193.70	4.90	193.09	3.66	193.19	3.48	193.68	3.80	**191.40**
TE-21-5-3-2	394.80	0.00	394.80	0.00	394.80	0.00	**363.63**	11.14	364.09	12.00	363.95	9.48	**330.60**
TE-21-5-3-3	600.00	0.00	600.00	0.00	600.00	0.00	532.51	16.99	**528.28**	15.87	528.71	17.24	**460.00**
TE-21-5-4-1	188.93	2.26	**188.55**	0.91	188.87	1.65	189.09	2.32	188.71	1.49	188.89	2.30	**185.80**
TE-21-5-4-2	450.80	0.00	450.80	0.00	450.80	0.00	**357.84**	15.10	364.25	16.98	361.29	15.23	**306.00**
TE-21-5-4-3	601.80	0.00	601.80	0.00	601.80	0.00	**522.59**	18.53	524.29	18.87	525.07	20.74	**459.20**
TE-21-5-5-1	188.08	1.37	188.29	1.64	**187.81**	0.78	187.97	1.04	188.12	1.18	188.34	1.53	**185.60**
TE-21-5-5-2	374.00	0.00	374.00	0.00	374.00	0.00	336.07	15.68	**332.77**	15.65	334.05	14.33	**274.80**
TE-21-5-5-3	609.60	0.00	609.60	0.00	609.60	0.00	507.92	19.40	507.28	19.22	**507.13**	16.97	**457.60**
TE-21-10-3-1	295.33	8.58	294.63	8.49	295.21	7.99	**294.29**	10.01	295.97	9.42	295.80	9.18	**281.20**
TE-21-10-3-2	666.80	0.00	666.80	0.00	666.80	0.00	562.10	18.72	561.72	19.04	**561.42**	18.50	**497.40**
TE-21-10-3-3	1007.00	0.00	1007.00	0.00	1007.00	0.00	834.71	27.07	**830.06**	26.64	830.88	27.18	**701.00**
TE-21-10-4-1	270.53	6.26	270.55	5.90	**269.65**	5.79	270.45	6.84	271.13	7.11	269.87	6.33	**261.20**
TE-21-10-4-2	591.00	0.00	591.00	0.00	591.00	0.00	523.65	18.40	**523.54**	18.17	524.28	18.60	**433.00**
TE-21-10-4-3	901.00	0.00	901.00	0.00	901.00	0.00	**774.07**	29.32	779.44	28.27	776.36	25.70	**615.60**
TE-21-10-5-1	261.55	6.36	260.52	5.20	**260.28**	6.29	261.19	5.62	261.60	6.25	260.57	6.47	**250.60**
TE-21-10-5-2	631.00	0.00	631.00	0.00	631.00	0.00	**479.10**	18.46	482.81	18.20	480.89	19.25	**398.60**
TE-21-10-5-3	848.40	0.00	848.40	0.00	848.40	0.00	727.17	28.35	727.77	28.66	**726.38**	26.24	**577.20**

Table 6.12: Average results over five instances (edge disjointness), regarding GRASP.

	GRASP												
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$		
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	**BOT**
TC-21-5-3-1	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**140.20**
TC-21-5-3-2	**278.51**	5.06	281.64	21.68	286.07	31.08	310.68	41.87	317.65	59.44	317.79	55.60	**237.80**
TC-21-5-3-3	**439.10**	11.26	446.27	24.56	448.68	32.44	465.04	48.12	479.35	56.67	480.80	55.83	**376.00**
TC-21-5-4-1	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**140.20**
TC-21-5-4-2	295.43	10.35	**247.04**	28.96	291.91	31.54	316.91	55.70	333.82	64.32	335.37	64.42	**237.80**
TC-21-5-4-3	**441.16**	10.62	450.55	28.19	459.33	49.80	486.92	65.75	500.32	73.10	512.03	84.60	**369.80**
TC-21-5-5-1	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**145.80**	0.00	**140.20**
TC-21-5-5-2	286.79	13.03	**286.03**	25.31	294.21	41.24	312.65	56.68	328.32	65.53	333.76	77.30	**222.60**
TC-21-5-5-3	464.49	6.11	**455.19**	32.25	462.07	47.61	492.43	76.26	515.33	77.56	529.53	92.23	**369.80**
TC-21-10-3-1	**244.40**	0.00	**244.40**	0.00	**244.40**	0.00	**244.40**	0.00	**244.40**	0.00	**244.40**	0.00	**233.00**
TC-21-10-3-2	**493.03**	14.62	496.23	27.74	527.65	44.83	595.81	64.15	637.76	81.00	649.71	85.03	**401.40**
TC-21-10-3-3	733.99	27.70	**730.84**	36.09	776.13	56.94	875.53	88.41	948.75	105.72	959.96	106.71	**577.20**
TC-21-10-4-1	**238.00**	0.00	**238.00**	0.00	**238.00**	0.00	**238.00**	0.00	**238.00**	0.00	**238.00**	0.00	**223.40**
TC-21-10-4-2	461.25	15.09	**459.17**	27.60	526.53	55.18	618.35	83.63	671.71	99.78	703.71	100.30	**362.60**
TC-21-10-4-3	**663.65**	20.98	682.91	35.77	767.52	64.80	912.47	103.32	1007.95	122.69	1027.57	156.03	**544.20**
TC-21-10-5-1	**236.20**	0.00	**236.20**	0.00	**236.20**	0.00	**236.20**	0.00	**236.20**	0.00	**236.20**	0.00	**222.60**
TC-21-10-5-2	**433.05**	16.85	443.69	34.03	529.39	61.86	618.79	91.18	698.91	107.51	703.17	121.49	**347.60**
TC-21-10-5-3	**662.11**	12.69	672.53	34.52	762.28	69.18	910.72	105.45	995.37	132.51	1033.70	136.83	**530.60**
TE-21-5-3-1	**203.20**	0.00	**203.20**	0.00	**203.20**	0.00	**203.20**	0.00	**203.20**	0.00	**203.20**	0.00	**191.40**
TE-21-5-3-2	411.53	8.80	**409.67**	20.62	413.83	28.31	427.73	39.98	452.31	57.67	451.51	55.87	**330.60**
TE-21-5-3-3	623.94	22.39	625.37	30.76	**619.33**	33.01	623.80	49.89	646.85	70.58	653.36	80.13	**460.00**
TE-21-5-4-1	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00	**185.80**
TE-21-5-4-2	**381.29**	7.94	389.73	20.78	403.01	36.36	413.40	51.07	435.02	68.50	441.76	75.23	**306.00**
TE-21-5-4-3	594.97	12.78	587.19	31.87	**584.13**	49.15	605.83	70.44	640.94	96.23	644.08	96.43	**459.20**
TE-21-5-5-1	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00	**193.80**	0.00	**185.60**
TE-21-5-5-2	**367.50**	10.66	371.71	18.71	387.39	37.55	400.71	58.77	414.12	73.75	431.65	82.93	**274.80**
TE-21-5-5-3	**562.56**	8.36	565.55	26.63	585.16	53.12	609.56	76.46	633.17	84.64	639.41	94.12	**457.60**
TE-21-10-3-1	**314.40**	0.00	**314.40**	0.00	**314.40**	0.00	**314.40**	0.00	**314.40**	0.00	**314.40**	0.00	**281.20**
TE-21-10-3-2	648.53	23.93	**647.03**	34.77	660.05	36.27	699.26	59.08	739.52	81.75	754.51	90.19	**497.40**
TE-21-10-3-3	**935.87**	28.93	942.99	41.26	960.65	49.78	1001.64	73.11	1071.17	97.05	1106.98	118.85	**701.00**
TE-21-10-4-1	**273.40**	0.00	**273.40**	0.00	**273.40**	0.00	**273.40**	0.00	**273.40**	0.00	**273.40**	0.00	**261.20**
TE-21-10-4-2	**550.96**	16.20	559.93	29.64	604.40	49.99	680.69	76.60	748.03	100.43	779.72	110.85	**433.00**
TE-21-10-4-3	**806.95**	17.50	826.76	37.45	875.49	67.08	1003.89	105.40	1086.49	120.78	1134.38	158.25	**615.60**
TE-21-10-5-1	**264.80**	0.00	**264.80**	0.00	**264.80**	0.00	**264.80**	0.00	**264.80**	0.00	**264.80**	0.00	**250.60**
TE-21-10-5-2	**507.31**	13.38	519.93	28.50	580.60	54.60	679.80	81.29	741.55	108.63	757.04	110.33	**398.60**
TE-21-10-5-3	**744.32**	19.45	767.66	34.58	848.13	64.39	987.25	104.24	1084.57	126.09	1120.05	150.20	**577.20**

The last four tables show the average results for edge disjointness.

Regarding edge disjointness, among constructive heuristics, CH3 and CH4 yield the best objective values, when $k_q = 1$, as can be seen from Table 6.9. If $k_q > 1$, then CH1 seems to perform best on average. This observation also holds for the SNDlib instances, as can be seen in Table A.73.

If the constructive heuristics are followed by the VND, one can observe from Table 6.10 that this previous mentioned partitioning does not hold any more. Here, CH2 with SH3F performs best on average if followed by a VND. Furthermore, the objective values have improved for each approach. As can be seen from Table A.75, VND with CH1 performs best on average regarding sparse graphs.

Regarding edge disjointness, the MSVND produces slightly better results with RCH4, the randomized CH4, than using RCH3. But as Table 6.11 shows, the results are on the average not far apart from each other. This also holds for the SNDlib instances, as can be seen in Table A.77.

The GRASP approach yields the best results with $\alpha = 0.0$ and $\alpha = 0.2$. Note that even for $\alpha = 0.0$ different solutions can be reached, since there can be edges with the same costs. The randomized CH1 now chooses one of these edges randomly, whereas CH1 takes always the next edge in the sorted list. This result also holds for the SNDlib instances, as can be seen in Table A.79. If all commodities have $k_q = 1$ the result is the same for all α, as only the shortest-hop-constrained-path algorithm is invoked.

Hence, one can draw essentially the same conclusions from the behavior of the implemented algorithms, regardless of whether node disjointness or edge disjointness.

It can be seen from Tables 6.9 to 6.12 that the VND and MSVND variants and the GRASP approach with small α-values provide a gap of about 5-25% on average, which are quite good results, keeping in mind, that all algorithms are very fast on average, except if the exact (non-polynomial) feasibility test is envoked often, as is the case with the instances which lasted longer than a couple of seconds. In some cases, as can be seen in Appendix A, the algorithms even hit the optimal results provided by Botton.

6.3.3 Results on the "big" instances

No we present the results for other TE and TC instances. We only test these bigger instances with a small set of algorithmic approaches, where we chose the simple VND with CH2-SH3F, as it worked best of all simple VND combinations regarding the previous instances. Furthermore we chose the MSVND using RCH4 and the GRASP approach with $\alpha = 0.0$ and $\alpha = 0.2$.

As can be seen from Tables 6.13 to 6.16, the MSVND approach with RCH4 works better on average than the GRASP approach on the larger instance sets. Moreover, the simple VND with CH2-SH3F also yields good results which are not far from the best results reached by the MSVND approach. Also regarding time consumation, the MSVND approach is significantly faster than the GRASP approach, but also here the time consumation is always noticeably lower than the time limit of 3600 seconds. Unfortunately, regarding the objective solution values there are no previously existing results to compare with.

Table 6.13: Results on "big" instance set TC (node disjointness).

	VND	**MSVND with**						**GRASP**			
	C2-S3F	RC4-S1		RC4-S2		RC4-S3F		$\alpha = 0.0$		$\alpha = 0.2$	
		μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TC-40-5-3-1	**120.00**	**120.00**	0.00	**120.00**	0.00	**120.00**	0.00	**120.00**	0.00	**120.00**	0.00
TC-40-5-3-2	233.00	220.23	1.28	**220.00**	0.00	221.10	3.48	256.60	15.46	262.93	21.73
TC-40-5-3-3	379.00	371.27	1.46	**371.00**	0.00	**371.00**	0.00	412.00	17.46	414.83	18.16
TC-40-5-4-1	**120.00**	**120.00**	0.00	**120.00**	0.00	**120.00**	0.00	**120.00**	0.00	**120.00**	0.00
TC-40-5-4-2	**220.00**	**220.00**	0.00	**220.00**	0.00	**220.00**	0.00	258.10	10.58	246.43	28.19
TC-40-5-4-3	379.00	372.07	2.77	**371.00**	0.00	371.27	1.46	397.00	0.00	405.23	19.40
TC-40-5-5-1	**120.00**	**120.00**	0.00	**120.00**	0.00	**120.00**	0.00	**120.00**	0.00	**120.00**	0.00
TC-40-5-5-2	**220.00**	**220.00**	0.00	**220.00**	0.00	220.23	1.28	240.40	15.82	251.87	27.29
TC-40-5-5-3	379.00	**371.00**	0.00	**371.00**	0.00	**371.00**	0.00	400.20	3.99	426.77	31.83
TC-40-10-3-1	259.00	245.00	5.99	245.47	5.69	**244.53**	6.33	259.00	0.00	259.00	0.00
TC-40-10-3-2	454.00	**438.57**	7.41	442.07	8.91	439.60	8.15	544.93	22.55	535.27	30.12
TC-40-10-3-3	682.00	**674.23**	10.66	678.00	13.83	677.00	11.32	776.83	25.32	771.90	37.61
TC-40-10-4-1	259.00	**246.27**	6.02	246.37	6.14	246.93	5.82	259.00	0.00	259.00	0.00
TC-40-10-4-2	432.00	419.93	5.96	420.87	5.49	**419.53**	6.06	508.90	27.04	497.57	34.79
TC-40-10-4-3	682.00	661.63	12.30	659.07	13.69	**655.13**	14.05	718.47	22.67	767.77	37.98
TC-40-10-5-1	259.00	246.10	6.77	247.20	6.28	**244.67**	5.84	259.00	0.00	259.00	0.00
TC-40-10-5-2	432.00	392.47	5.41	**391.93**	3.89	393.03	6.33	477.93	14.17	509.70	44.29
TC-40-10-5-3	682.00	658.37	12.78	**657.23**	14.08	657.60	12.76	741.93	40.44	763.00	57.45
TC-60-5-3-1	**151.00**	**151.00**	0.00	**151.00**	0.00	**151.00**	0.00	**151.00**	0.00	**151.00**	0.00
TC-60-5-3-2	291.00	272.13	11.86	**271.50**	13.14	272.30	12.70	325.40	1.22	309.13	27.35
TC-60-5-3-3	436.00	**430.97**	7.98	435.63	4.57	431.70	7.91	479.40	12.40	467.90	29.78
TC-60-5-4-1	**151.00**	**151.00**	0.00	**151.00**	0.00	**151.00**	0.00	**151.00**	0.00	**151.00**	0.00
TC-60-5-4-2	291.00	270.37	11.85	272.50	12.57	**270.20**	10.92	318.77	23.80	289.30	26.06
TC-60-5-4-3	436.00	434.47	5.89	433.27	7.64	**430.90**	9.25	445.70	16.21	446.07	30.15
TC-60-5-5-1	**151.00**	**151.00**	0.00	**151.00**	0.00	**151.00**	0.00	**151.00**	0.00	**151.00**	0.00
TC-60-5-5-2	291.00	**266.90**	8.64	269.23	10.28	267.83	10.77	279.97	26.06	276.17	24.70
TC-60-5-5-3	436.00	432.13	7.51	**431.50**	7.71	432.87	7.40	446.90	23.24	433.23	28.48
TC-60-10-3-1	214.00	200.73	4.47	199.73	4.36	**199.47**	4.27	214.00	0.00	214.00	0.00
TC-60-10-3-2	417.00	390.50	11.69	390.67	12.19	**388.67**	11.88	442.53	10.51	461.67	29.59
TC-60-10-3-3	596.00	570.00	12.43	569.43	16.33	**566.33**	13.90	645.60	13.38	665.50	32.49
TC-60-10-4-1	211.00	200.23	4.08	**198.33**	3.03	200.03	4.06	211.00	0.00	211.00	0.00
TC-60-10-4-2	397.00	**374.10**	8.31	374.83	10.59	373.53	11.96	425.07	3.95	453.53	34.29
TC-60-10-4-3	581.00	555.93	11.38	**554.97**	10.92	555.10	12.85	631.03	53.11	654.73	45.05
TC-60-10-5-1	211.00	199.40	3.25	199.00	3.15	**198.60**	3.94	211.00	0.00	211.00	0.00
TC-60-10-5-2	380.00	362.50	11.85	**361.80**	12.16	365.83	8.83	390.60	21.40	446.90	42.76
TC-60-10-5-3	581.00	553.73	14.02	**550.33**	12.23	552.20	13.31	609.40	14.82	640.03	46.92
TC-80-5-3-1	**194.00**	**194.00**	0.00	194.53	2.92	**194.00**	0.00	**194.00**	0.00	**194.00**	0.00
TC-80-5-3-2	383.00	371.60	9.47	**368.43**	8.17	368.70	10.60	389.87	13.77	390.13	22.88
TC-80-5-3-3	564.00	**532.60**	7.93	535.47	11.20	540.07	13.59	588.23	15.92	604.70	20.32
TC-80-5-4-1	**194.00**	**194.00**	0.00	**194.00**	0.00	194.73	4.02	**194.00**	0.00	**194.00**	0.00
TC-80-5-4-2	383.00	**340.00**	0.00	**340.00**	0.00	**340.00**	0.00	409.47	5.27	376.03	30.44
TC-80-5-4-3	564.00	518.53	4.59	517.70	4.81	**517.50**	3.92	598.83	8.10	581.27	28.60
TC-80-5-5-1	**194.00**	**194.00**	0.00	**194.00**	0.00	**194.00**	0.00	**194.00**	0.00	**194.00**	0.00
TC-80-5-5-2	383.00	**340.00**	0.00	**340.00**	0.00	**340.00**	0.00	355.97	25.22	374.63	19.28
TC-80-5-5-3	564.00	518.43	5.18	518.40	4.30	**518.20**	4.79	548.33	8.44	571.87	28.58
TC-80-10-3-1	**274.00**	274.60	1.83	274.40	1.52	274.63	2.58	**274.00**	0.00	**274.00**	0.00
TC-80-10-3-2	546.00	540.70	6.72	**538.53**	7.61	539.10	7.10	628.03	21.97	619.67	39.34
TC-80-10-3-3	845.00	**775.10**	19.10	780.07	20.63	785.67	15.10	957.00	36.49	948.53	49.12
TC-80-10-4-1	**274.00**	274.20	1.10	274.63	2.58	274.20	1.10	**274.00**	0.00	**274.00**	0.00
TC-80-10-4-2	530.00	486.17	7.59	489.77	12.71	**484.43**	7.05	619.67	24.33	599.17	41.29
TC-80-10-4-3	845.00	760.47	14.41	**756.97**	14.64	757.63	15.09	896.47	33.57	896.10	50.80
TC-80-10-5-1	**274.00**	274.63	2.58	275.03	3.72	274.60	1.83	**274.00**	0.00	**274.00**	0.00
TC-80-10-5-2	495.00	468.47	14.37	467.77	14.42	**464.03**	12.56	562.70	36.32	583.60	46.17
TC-80-10-5-3	845.00	**735.53**	16.21	742.17	17.66	738.87	16.69	809.40	39.26	892.20	47.62

Table 6.14: Time consumation (s) on “big” instance set TC (node disjointness).

	VND	**MSVND with**						**GRASP**			
	C2-S3F	RC4-S1		RC4-S2		RC4-S3F		$\alpha = 0.0$		$\alpha = 0.2$	
		μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TC-40-5-3-1	0.14	0.90	0.08	0.92	0.08	0.90	0.07	0.15	0.00	0.15	0.00
TC-40-5-3-2	0.36	2.63	0.21	2.75	0.20	2.73	0.20	2.48	0.13	1.94	0.65
TC-40-5-3-3	0.37	3.24	0.26	3.09	0.27	3.09	0.23	3.05	0.23	3.20	0.48
TC-40-5-4-1	0.16	1.01	0.08	1.05	0.08	1.05	0.09	0.17	0.01	0.17	0.01
TC-40-5-4-2	0.56	3.55	0.36	3.58	0.22	3.48	0.33	1.94	0.15	1.73	0.59
TC-40-5-4-3	0.44	3.57	0.43	3.60	0.33	3.78	0.67	3.32	0.22	2.64	0.72
TC-40-5-5-1	0.19	1.21	0.09	1.18	0.07	1.23	0.08	0.20	0.00	0.20	0.01
TC-40-5-5-2	0.63	3.97	0.35	3.94	0.36	3.98	0.37	2.14	0.23	1.64	0.61
TC-40-5-5-3	0.50	4.13	0.40	4.19	0.42	4.13	0.43	4.25	0.33	3.06	0.73
TC-40-10-3-1	0.60	3.36	0.21	3.37	0.22	3.29	0.26	0.62	0.00	0.62	0.00
TC-40-10-3-2	1.56	10.04	0.50	10.20	0.63	9.98	0.50	4.85	0.29	3.98	0.81
TC-40-10-3-3	2.56	14.77	0.69	14.69	0.87	14.91	0.96	6.41	0.45	6.09	0.94
TC-40-10-4-1	0.71	3.58	0.34	3.61	0.29	3.64	0.30	0.72	0.00	0.72	0.00
TC-40-10-4-2	2.25	13.90	0.83	13.32	0.78	13.74	0.59	3.86	0.52	3.83	0.68
TC-40-10-4-3	2.91	18.91	1.57	18.43	1.05	18.53	1.02	6.71	0.21	5.85	0.90
TC-40-10-5-1	0.80	4.12	0.36	4.13	0.35	4.11	0.27	0.82	0.00	0.82	0.04
TC-40-10-5-2	2.54	16.57	0.80	16.84	0.77	16.63	0.79	3.94	0.30	4.00	0.86
TC-40-10-5-3	3.32	21.93	1.35	21.51	1.39	21.73	1.61	8.42	0.50	7.47	1.51
TC-60-5-3-1	0.18	1.49	0.15	1.58	0.15	1.52	0.14	0.19	0.01	0.19	0.01
TC-60-5-3-2	0.74	5.14	0.46	4.95	0.47	4.83	0.35	6.75	0.32	3.86	1.54
TC-60-5-3-3	1.27	5.97	0.63	5.70	0.68	6.11	0.69	8.97	0.55	6.59	1.68
TC-60-5-4-1	0.21	1.82	0.11	1.80	0.14	1.81	0.17	0.22	0.01	0.23	0.01
TC-60-5-4-2	0.83	5.68	0.41	5.65	0.50	5.60	0.46	7.18	0.40	3.03	1.16
TC-60-5-4-3	1.45	6.68	0.93	6.74	0.75	6.70	0.78	8.81	0.51	5.73	1.73
TC-60-5-5-1	0.24	2.10	0.20	2.03	0.16	1.99	0.20	0.26	0.00	0.26	0.01
TC-60-5-5-2	0.94	6.32	0.59	6.43	0.50	6.43	0.41	6.98	0.98	3.15	1.08
TC-60-5-5-3	1.68	8.28	1.08	7.72	0.89	8.06	1.23	10.67	0.59	6.06	1.33
TC-60-10-3-1	1.01	7.49	0.53	7.35	0.72	7.42	0.87	1.02	0.00	1.02	0.00
TC-60-10-3-2	2.80	16.64	1.00	17.18	1.11	16.42	1.03	19.18	1.55	17.27	4.89
TC-60-10-3-3	3.85	27.54	1.70	27.69	2.65	27.86	2.21	26.54	1.47	27.22	2.32
TC-60-10-4-1	1.43	7.64	0.78	7.73	0.67	7.60	0.68	1.45	0.01	1.45	0.00
TC-60-10-4-2	3.61	23.01	1.39	22.80	0.94	23.01	1.45	16.46	1.18	11.24	3.99
TC-60-10-4-3	5.66	37.02	2.72	37.01	2.67	37.02	2.43	23.24	1.57	17.90	3.23
TC-60-10-5-1	1.64	8.80	0.74	8.74	0.63	8.94	0.53	1.64	0.01	1.65	0.00
TC-60-10-5-2	4.99	29.33	1.44	29.12	1.48	29.49	1.27	16.34	1.35	9.97	2.60
TC-60-10-5-3	6.40	43.54	3.02	44.38	3.15	42.69	2.85	21.23	1.32	19.01	5.59
TC-80-5-3-1	0.48	3.32	0.37	3.31	0.39	3.28	0.42	0.50	0.01	0.50	0.01
TC-80-5-3-2	1.87	11.28	0.37	11.25	0.41	11.26	0.35	17.69	1.06	10.27	3.51
TC-80-5-3-3	2.68	19.17	1.98	18.99	1.72	19.52	1.53	25.60	1.98	15.68	3.69
TC-80-5-4-1	0.57	3.40	0.20	3.35	0.22	3.41	0.18	0.60	0.00	0.60	0.00
TC-80-5-4-2	2.15	16.40	1.12	17.28	1.29	16.92	1.19	12.03	0.85	7.91	2.12
TC-80-5-4-3	3.11	23.83	1.78	23.12	1.94	23.45	1.38	16.95	0.89	11.82	3.40
TC-80-5-5-1	0.65	3.78	0.18	3.85	0.23	3.91	0.20	0.68	0.00	0.68	0.00
TC-80-5-5-2	2.37	18.28	1.20	18.28	1.15	18.67	1.43	11.91	1.32	6.95	2.05
TC-80-5-5-3	3.60	26.49	1.77	26.72	2.58	26.83	2.03	18.75	1.93	13.42	3.92
TC-80-10-3-1	2.46	11.66	1.04	11.35	0.95	11.53	1.10	2.46	0.01	2.46	0.00
TC-80-10-3-2	7.12	33.58	1.89	33.06	2.20	32.35	1.80	31.22	1.39	22.83	6.62
TC-80-10-3-3	10.28	56.38	4.19	57.58	3.59	56.82	3.93	44.15	3.00	31.71	5.48
TC-80-10-4-1	2.88	13.12	1.06	13.13	1.04	12.86	0.89	2.88	0.01	2.88	0.01
TC-80-10-4-2	8.89	51.17	2.87	50.50	3.24	50.87	2.91	25.29	2.62	17.06	4.21
TC-80-10-4-3	11.91	76.72	5.23	76.15	4.63	74.41	4.12	35.93	3.10	27.59	5.09
TC-80-10-5-1	3.29	15.04	1.33	14.70	1.25	15.47	1.01	3.33	0.01	3.33	0.01
TC-80-10-5-2	10.58	62.44	3.58	61.92	3.53	61.89	3.15	26.03	4.37	20.57	6.57
TC-80-10-5-3	14.18	90.63	6.56	89.79	5.44	93.76	6.43	44.78	3.98	32.84	6.91

Table 6.15: Results on "big" instance set TE (node disjointness).

	VND	**MSVND with**						**GRASP**			
	C2-S3F	RC4-S1		RC4-S2		RC4-S3F		$\alpha = 0.0$		$\alpha = 0.2$	
		μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TE-40-5-3-1	**181.00**	**181.00**	0.00	**181.00**	0.00	181.07	0.37	**181.00**	0.00	**181.00**	0.00
TE-40-5-3-2	375.00	365.87	8.70	**364.80**	8.46	365.93	10.88	452.30	14.98	438.30	27.13
TE-40-5-3-3	563.00	517.77	9.96	**515.83**	4.49	516.03	6.40	676.67	24.48	653.83	33.16
TE-40-5-4-1	**181.00**	**181.00**	0.00	**181.00**	0.00	**181.00**	0.00	**181.00**	0.00	**181.00**	0.00
TE-40-5-4-2	335.00	305.67	13.79	304.67	13.59	**301.27**	12.85	399.40	18.65	396.87	25.00
TE-40-5-4-3	483.00	**461.77**	9.22	462.40	7.84	462.67	9.93	584.20	41.00	586.97	41.82
TE-40-5-5-1	**181.00**	**181.00**	0.00	**181.00**	0.00	**181.00**	0.00	**181.00**	0.00	**181.00**	0.00
TE-40-5-5-2	291.00	257.27	9.54	**256.00**	7.12	259.33	9.57	360.83	47.84	353.37	43.52
TE-40-5-5-3	483.00	**461.00**	8.38	462.53	8.04	463.47	10.16	493.30	14.82	518.27	41.04
TE-40-10-3-1	**267.00**	269.60	3.55	271.03	4.25	270.93	3.60	**267.00**	0.00	**267.00**	0.00
TE-40-10-3-2	**599.00**	606.63	11.43	606.73	12.68	603.20	10.25	729.13	20.60	730.90	27.03
TE-40-10-3-3	**861.00**	883.33	27.75	885.23	25.68	886.23	26.11	1097.07	23.67	1086.80	35.38
TE-40-10-4-1	**267.00**	271.87	6.91	270.67	4.47	273.27	7.43	**267.00**	0.00	**267.00**	0.00
TE-40-10-4-2	569.00	527.90	13.94	522.23	14.64	**521.50**	15.69	666.67	22.19	675.07	29.91
TE-40-10-4-3	776.00	**775.33**	27.52	781.03	26.71	**775.33**	19.47	1004.37	34.80	992.47	48.16
TE-40-10-5-1	**267.00**	271.73	5.21	273.63	5.86	273.00	7.56	**267.00**	0.00	**267.00**	0.00
TE-40-10-5-2	503.00	483.13	15.46	**482.27**	17.30	484.27	18.38	627.70	16.52	591.13	42.91
TE-40-10-5-3	743.00	734.70	25.88	**724.13**	23.77	733.43	23.72	921.77	12.19	896.90	48.78
TE-60-5-3-1	293.00	287.50	1.38	287.30	1.21	**287.10**	0.55	293.00	0.00	293.00	0.00
TE-60-5-3-2	663.00	607.93	13.70	**606.50**	15.19	619.10	21.01	728.50	6.00	720.00	27.20
TE-60-5-3-3	887.00	**885.30**	32.53	902.53	36.83	898.40	37.36	1091.60	7.41	1100.67	46.46
TE-60-5-4-1	293.00	**287.20**	1.10	287.40	1.30	**287.20**	0.76	293.00	0.00	293.00	0.00
TE-60-5-4-2	619.00	**540.87**	15.71	541.07	10.86	538.30	13.21	571.67	14.19	590.80	42.38
TE-60-5-4-3	885.00	854.43	34.88	850.07	34.85	**847.40**	34.10	968.27	100.16	906.83	62.56
TE-60-5-5-1	293.00	**287.50**	1.38	287.60	1.65	287.70	1.51	293.00	0.00	293.00	0.00
TE-60-5-5-2	605.00	526.30	14.50	**526.00**	14.70	531.30	16.59	580.77	27.62	565.23	24.91
TE-60-5-5-3	848.00	810.30	23.63	819.37	22.19	**809.83**	21.70	906.57	29.09	887.50	42.80
TE-60-10-3-1	409.00	389.53	9.29	386.53	7.17	**383.73**	6.38	409.00	0.00	409.00	0.00
TE-60-10-3-2	901.00	929.20	17.63	**925.03**	19.01	933.10	24.15	1067.23	16.75	1098.83	39.60
TE-60-10-3-3	1372.00	1359.80	56.73	1340.83	52.78	**1331.90**	54.08	1654.13	13.19	1637.60	50.65
TE-60-10-4-1	409.00	**388.53**	7.46	391.00	8.20	389.03	8.95	409.00	0.00	409.00	0.00
TE-60-10-4-2	830.00	816.53	27.57	**806.67**	32.04	814.30	27.30	1027.53	20.75	985.53	61.25
TE-60-10-4-3	1227.00	1186.47	33.64	**1184.73**	40.72	1194.03	54.09	1552.67	71.15	1478.77	103.03
TE-60-10-5-1	409.00	392.73	11.41	**392.47**	9.78	397.47	8.46	409.00	0.00	409.00	0.00
TE-60-10-5-2	761.00	738.03	21.13	**734.00**	23.12	735.47	19.96	878.50	34.37	884.17	73.29
TE-60-10-5-3	1227.00	**1101.87**	48.75	1103.87	36.62	1113.50	37.91	1348.00	69.60	1283.17	109.77
TE-80-5-3-1	320.00	288.87	17.07	290.30	16.79	**285.63**	12.96	320.00	0.00	320.00	0.00
TE-80-5-3-2	557.00	613.53	42.64	623.80	40.79	**603.00**	40.27	820.57	10.07	798.87	37.13
TE-80-5-3-3	974.00	911.63	21.49	**905.70**	16.28	906.97	20.79	1230.43	22.94	1208.40	49.01
TE-80-5-4-1	320.00	289.20	16.62	**288.83**	14.70	290.23	17.78	320.00	0.00	320.00	0.00
TE-80-5-4-2	**555.00**	559.10	10.19	555.57	3.33	559.40	9.91	611.20	29.20	654.93	48.46
TE-80-5-4-3	974.00	**832.73**	24.44	838.70	28.48	836.47	27.60	932.30	22.67	968.10	46.31
TE-80-5-5-1	320.00	**289.23**	13.08	296.83	17.16	295.50	20.01	320.00	0.00	320.00	0.00
TE-80-5-5-2	555.00	526.60	27.76	**523.97**	23.42	524.50	22.69	576.87	14.75	585.97	35.54
TE-80-5-5-3	974.00	801.73	14.51	**799.40**	12.08	807.37	19.83	906.47	65.37	928.20	67.52
TE-80-10-3-1	501.00	**473.07**	8.13	475.80	10.84	474.17	8.13	501.00	0.00	501.00	0.00
TE-80-10-3-2	**1031.00**	1061.20	32.14	1073.70	29.82	1058.03	27.28	1314.20	15.33	1256.23	45.57
TE-80-10-3-3	**1344.00**	1549.73	45.83	1550.13	47.06	1551.37	42.98	1951.13	31.07	1891.70	56.22
TE-80-10-4-1	501.00	475.00	11.25	477.20	13.80	**472.93**	11.23	501.00	0.00	501.00	0.00
TE-80-10-4-2	934.00	933.17	36.43	**917.80**	26.41	920.30	28.51	1132.00	27.68	1123.63	42.68
TE-80-10-4-3	**1315.00**	1363.63	55.37	1369.83	48.90	1341.77	52.11	1673.30	18.36	1685.30	69.73
TE-80-10-5-1	501.00	473.27	11.84	**471.83**	12.55	477.17	12.81	501.00	0.00	501.00	0.00
TE-80-10-5-2	833.00	839.03	26.86	836.53	32.27	**829.23**	35.32	1035.30	27.31	1030.87	58.50
TE-80-10-5-3	1311.00	1266.40	36.03	**1251.17**	47.69	1265.87	35.58	1484.30	90.41	1528.07	104.39

Table 6.16: Time consumation (s) on "big" instance set TE (node disjointness).

	VND	**MSVND with**						**GRASP**			
	C2-S3F	RC4-S1		RC4-S2		RC4-S3F		$\alpha = 0.0$		$\alpha = 0.2$	
		μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TE-40-5-3-1	0.23	1.24	0.09	1.22	0.09	1.26	0.15	0.24	0.01	0.24	0.01
TE-40-5-3-2	0.37	2.09	0.12	2.07	0.13	2.07	0.16	6.51	0.19	5.62	0.67
TE-40-5-3-3	0.54	3.53	0.35	3.49	0.24	3.54	0.24	7.39	0.28	6.47	0.68
TE-40-5-4-1	0.26	1.24	0.12	1.23	0.11	1.25	0.14	0.27	0.00	0.27	0.00
TE-40-5-4-2	0.41	3.37	0.33	3.33	0.25	3.41	0.22	4.18	0.19	4.04	0.30
TE-40-5-4-3	0.82	5.27	0.27	5.26	0.28	5.27	0.30	5.07	0.33	4.98	0.32
TE-40-5-5-1	0.30	1.46	0.13	1.44	0.13	1.39	0.13	0.31	0.00	0.31	0.01
TE-40-5-5-2	0.62	4.59	0.28	4.53	0.25	4.60	0.28	2.98	0.36	2.26	0.63
TE-40-5-5-3	0.94	6.05	0.29	6.07	0.28	6.11	0.31	3.95	0.25	4.09	0.69
TE-40-10-3-1	0.69	4.25	0.32	4.13	0.34	4.16	0.28	0.71	0.00	0.71	0.00
TE-40-10-3-2	1.50	6.11	0.47	6.19	0.50	6.04	0.46	11.64	0.32	10.41	0.96
TE-40-10-3-3	2.44	10.36	0.73	10.79	1.00	10.63	0.86	13.36	0.38	12.62	1.31
TE-40-10-4-1	0.80	3.93	0.30	3.97	0.28	3.97	0.26	0.83	0.01	0.83	0.01
TE-40-10-4-2	1.87	9.34	0.59	9.18	0.57	9.14	0.58	7.60	0.51	7.83	0.66
TE-40-10-4-3	3.55	16.83	1.08	16.80	0.99	16.81	0.80	9.31	0.55	9.77	0.75
TE-40-10-5-1	0.91	4.09	0.32	4.19	0.28	4.13	0.20	0.94	0.01	0.94	0.00
TE-40-10-5-2	2.72	12.90	0.77	12.84	0.70	12.66	0.90	5.45	0.35	5.34	1.00
TE-40-10-5-3	4.31	21.48	1.16	21.86	1.43	21.94	1.15	7.88	0.47	9.05	2.00
TE-60-5-3-1	0.38	2.77	0.21	2.82	0.23	2.82	0.22	0.40	0.00	0.40	0.00
TE-60-5-3-2	1.11	4.94	0.58	4.82	0.76	4.88	0.73	22.63	0.71	20.98	2.53
TE-60-5-3-3	1.55	8.01	0.65	7.93	0.80	7.90	0.68	27.51	0.70	25.74	3.07
TE-60-5-4-1	0.43	2.63	0.33	2.37	0.32	2.58	0.38	0.45	0.00	0.46	0.01
TE-60-5-4-2	1.26	6.91	0.68	7.06	0.81	6.99	0.89	15.07	1.01	9.98	2.53
TE-60-5-4-3	2.09	10.28	1.16	10.26	1.01	10.43	1.08	18.20	1.71	16.98	3.30
TE-60-5-5-1	0.50	2.48	0.23	2.41	0.27	2.58	0.34	0.52	0.00	0.52	0.00
TE-60-5-5-2	1.40	8.66	0.73	8.48	0.66	8.80	0.67	13.32	0.75	8.02	2.57
TE-60-5-5-3	2.38	15.17	1.78	14.45	1.40	14.86	1.74	24.56	9.81	18.55	10.80
TE-60-10-3-1	1.60	11.88	0.85	11.97	0.62	11.74	0.70	1.62	0.01	1.62	0.00
TE-60-10-3-2	3.17	12.60	1.35	12.52	1.20	12.56	1.00	47.28	1.13	42.33	4.71
TE-60-10-3-3	5.70	22.26	2.40	21.49	1.40	21.82	2.41	53.24	1.29	51.62	6.17
TE-60-10-4-1	1.59	10.32	1.07	10.20	1.32	10.17	0.86	1.65	0.01	1.65	0.01
TE-60-10-4-2	4.09	18.26	1.52	18.04	1.60	17.95	1.44	23.49	1.55	17.15	4.57
TE-60-10-4-3	7.28	35.46	2.66	35.62	2.78	34.76	2.71	29.61	2.43	31.48	5.78
TE-60-10-5-1	1.84	9.77	0.80	9.72	0.69	9.59	0.79	1.87	0.01	1.87	0.01
TE-60-10-5-2	5.13	25.73	1.86	25.33	1.49	26.03	2.00	23.98	1.23	13.96	3.15
TE-60-10-5-3	8.56	48.49	3.46	48.65	3.74	47.84	3.19	47.93	26.70	33.87	15.69
TE-80-5-3-1	0.68	4.86	0.39	4.81	0.38	4.87	0.50	0.71	0.00	0.71	0.01
TE-80-5-3-2	2.08	9.82	0.88	9.79	0.80	10.16	0.77	86.65	1.32	86.69	9.19
TE-80-5-3-3	2.60	17.85	1.74	17.68	1.26	17.90	1.61	101.29	2.44	95.29	11.24
TE-80-5-4-1	0.80	4.37	0.49	4.16	0.41	4.31	0.44	0.83	0.01	0.84	0.01
TE-80-5-4-2	2.37	15.60	1.29	15.59	1.57	15.45	1.49	63.77	1.73	68.96	6.68
TE-80-5-4-3	3.05	25.92	2.55	25.10	2.25	25.10	2.20	82.44	4.78	78.84	6.29
TE-80-5-5-1	0.90	4.40	0.44	4.41	0.35	4.31	0.45	0.93	0.00	0.93	0.01
TE-80-5-5-2	2.72	19.80	0.91	20.06	1.25	19.73	1.21	40.48	2.03	23.04	7.62
TE-80-5-5-3	3.51	32.93	2.48	31.84	3.40	31.32	2.69	53.68	4.16	37.96	12.75
TE-80-10-3-1	2.63	20.48	1.64	20.90	1.38	19.96	1.44	2.68	0.02	2.67	0.01
TE-80-10-3-2	5.75	26.48	2.51	27.19	3.00	27.02	2.84	160.49	12.24	156.08	15.59
TE-80-10-3-3	13.35	45.03	4.40	46.94	4.63	47.35	5.16	187.69	6.31	181.06	19.02
TE-80-10-4-1	3.05	18.17	1.64	18.06	1.55	18.18	1.41	3.11	0.01	3.11	0.01
TE-80-10-4-2	8.29	39.79	3.80	40.26	3.53	41.80	3.43	110.89	2.37	117.54	7.94
TE-80-10-4-3	15.35	72.17	6.38	70.06	5.96	72.32	6.09	133.85	7.45	140.81	12.11
TE-80-10-5-1	3.47	18.97	1.41	19.71	1.66	19.02	1.60	3.54	0.00	3.54	0.00
TE-80-10-5-2	9.40	57.98	4.08	58.31	3.30	58.84	3.85	72.26	4.12	43.27	13.32
TE-80-10-5-3	17.13	102.79	6.19	106.45	9.69	99.74	7.88	96.03	6.41	74.32	26.24

Chapter 7

Concluding remarks

In this thesis, heuristic and meta-heuristic algorithms for solving the Hop Constraind Node Survivable Network Design Problem (HNSND) and the Hop Constrained Edge Survivable Network Design Problem (HESND) have been introduced.

Hop constrained survivable network design is an *NP*-hard problem. Hence, we must be able to check in polynomial time, if a given solution is a feasible solution, given an appropriate solution representation. Encoding the solution as a set of disjoint paths with certain restrictions fits these needs, but defining appropriate operators on encoded solutions is far from trivial in this case. On the other hand, encoding the solution as a subgraph raises the problem, that the feasibility test can not be done in polynomial time, it is even for itself *NP*-hard. Nevertheless, we chose the second alternative and hence, the first main focus was developing a (fast) advanced feasibility check, which checks in polynomial time that at least a given solution provably is not feasible, at best with a very small error rate, in order to minimize applications of the time-consuming exact feasibility test.

As can be seen in the previous chapter, the advanced feasibility check yields quite good results in practice, irrespective of whether using complete graphs or sparse graphs and whether a big or a small number of commodities needs to be fulfilled. On average, the number of true negatives is about two third, i.e. the advanced feasibility cuts off two third of all tested solutions rightly as infeasible ones. Furthermore, the number of false positives is about 1%, i.e. in only about one percent of all solutions, which were evaluated to true, the advanced feasibility check was wrong. Hence, the upper bound, we check against, is quite good after all, although it is in principle a very rough upper bound. Therefore, the advanced feasibility check can be used for situations, where a fast algorithm is needed and generating infeasible solutions is acceptable with an error rate of about 1% or more. Furthermore, this algorithm has a total error rate of about 0,40% over all tested instances.

We then developed 27 different problem solution algorithms, including ten constructive heuristic variants, ten VND variants, six MSVND variants and a GRASP approach. In addition, we presented four different algorithms for solving a single commodity, as well as an improved exact feasibility test and two sophisticated neighborhood structures that fit the needs for this complex network design problem.

Computational results show that some methods meet the optimal results provided by Botton. On a general view, for the edge-disjointness variant, the VND and MSVND variants and the GRASP approach with small α-values provide a gap of about 5-25% on average, which are quite good results, keeping in mind, that all algorithms are very fast on average, except if the exact (non-polynomial) feasibility test is envoked often, as is the case with the instances which lasted longer than a couple of seconds. Also on the "big" instance sets, the tested algorithms work fast on average. Furthermore, it can be seen from the computational results on the "big" instance sets that the MSVND approach yields better results than the GRASP approach and is significantly faster.

It should be easy to modify the provided algorithms, in order to use them for evolved and more complex problem variants, as were outlined in the thesis. Future work could also lie in the refinement of the advanced feasibility check, i.e. further closing the gap of about 1% false positives, as it is not completely out of the question that there could be found tighter upper bounds. Moreover, future work could lie in developing more neighborhood structures for the VND.

Finally, it can be said that this thesis provides a big toolbox of heuristic methods for solving hop constrained network design problems, which yield good results in a reasonable amount of time.

Appendix A

Detailed result tables

In this appendix the detailed result tables for the TC-5, TC-10, TE-5 and TE-10 instance sets, as well as for the SNDlib instance sets, regarding node disjointness as well as edge disjointness are presented. Tables A.1 to A.40 show the results on mentioned test sets for the node disjointness solution algorithms, whereas Tables A.41 to A.80 show the results on the mentioned test sets for the edge disjointness solution algorithms, where we additionally present the results of Botton (abbreviated by *BOT*) for comparison reasons, regarding the TC and TE instance sets. To save space we omitted the "H" in all abbreviations, e.g. CH1 is in the tables abbreviated with C1.

The computations were performed on a single core of an Intel Xeon E5540 processor with 2.53 GHz and 3GB RAM, with a time limit of 3600 seconds. The result tables also show the time consumation in seconds.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TC-21-5-1-3-1	153	153	153	153	136	136	136	136	136	136
TC-21-5-2-3-1	221	221	221	221	174	174	174	174	174	174
TC-21-5-3-3-1	198	198	198	198	108	108	108	108	108	108
TC-21-5-4-3-1	221	221	221	221	184	184	184	184	184	184
TC-21-5-5-3-1	201	201	201	201	171	171	171	171	171	171
TC-21-5-1-3-2	274	456	294	301	456	294	266	266	266	266
TC-21-5-2-3-2	385	471	435	462	471	439	385	385	385	385
TC-21-5-3-3-2	252	376	417	346	376	386	285	285	285	285
TC-21-5-4-3-2	353	639	367	399	639	367	358	358	358	358
TC-21-5-5-3-2	315	575	437	391	575	345	333	333	333	333
TC-21-5-1-3-3	388	738	495	448	738	428	427	427	427	427
TC-21-5-2-3-3	577	744	600	690	744	623	597	597	597	597
TC-21-5-3-3-3	478	516	653	509	516	622	460	460	460	460
TC-21-5-4-3-3	509	1067	674	603	1067	523	581	581	581	581
TC-21-5-5-3-3	541	921	658	651	921	545	552	552	552	552
TC-21-5-1-4-1	153	153	153	153	136	136	136	136	136	136
TC-21-5-2-4-1	221	221	221	221	174	174	174	174	174	174
TC-21-5-3-4-1	198	198	198	198	108	108	108	108	108	108
TC-21-5-4-4-1	221	221	221	221	184	184	184	184	184	184
TC-21-5-5-4-1	201	201	201	201	171	171	171	171	171	171
TC-21-5-1-4-2	273	456	297	301	456	297	266	266	266	266
TC-21-5-2-4-2	414	471	450	462	471	430	385	385	385	385
TC-21-5-3-4-2	304	376	442	346	376	392	285	285	285	285
TC-21-5-4-4-2	331	639	367	399	639	345	358	358	358	358
TC-21-5-5-4-2	419	575	471	391	575	471	333	333	333	333
TC-21-5-1-4-3	439	738	511	448	738	469	427	427	427	427
TC-21-5-2-4-3	541	744	605	690	744	605	597	597	597	597
TC-21-5-3-4-3	485	516	568	509	516	537	460	460	460	460
TC-21-5-4-4-3	513	1067	761	603	1067	556	581	581	581	581
TC-21-5-5-4-3	523	921	666	651	921	567	552	552	552	552
TC-21-5-1-5-1	153	153	153	153	136	136	136	136	136	136
TC-21-5-2-5-1	221	221	221	221	174	174	174	174	174	174
TC-21-5-3-5-1	198	198	198	198	108	108	108	108	108	108
TC-21-5-4-5-1	221	221	221	221	184	184	184	184	184	184
TC-21-5-5-5-1	201	201	201	201	171	171	171	171	171	171
TC-21-5-1-5-2	263	456	297	301	456	297	266	266	266	266
TC-21-5-2-5-2	368	471	444	462	471	390	385	385	385	385
TC-21-5-3-5-2	296	376	360	346	376	360	285	285	285	285
TC-21-5-4-5-2	331	639	367	399	639	345	358	358	358	358
TC-21-5-5-5-2	371	575	459	391	575	421	333	333	333	333
TC-21-5-1-5-3	425	738	511	448	738	469	427	427	427	427
TC-21-5-2-5-3	509	744	587	690	744	541	597	597	597	597
TC-21-5-3-5-3	412	516	599	509	516	568	460	460	460	460
TC-21-5-4-5-3	523	1067	746	603	1067	634	581	581	581	581
TC-21-5-5-5-3	490	921	672	651	921	526	552	552	552	552

Table A.1: Results for node-disjointness on TC-21-5 instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TC-21-5-1-3-1	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01
TC-21-5-2-3-1	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TC-21-5-3-3-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
TC-21-5-4-3-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
TC-21-5-5-3-1	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01
TC-21-5-1-3-2	0.17	0.01	0.08	0.01	0.00	0.09	0.00	0.01	0.01	0.01
TC-21-5-2-3-2	0.37	0.00	0.21	0.01	0.01	0.26	0.01	0.01	0.00	0.00
TC-21-5-3-3-2	0.30	0.01	0.20	0.00	0.01	0.16	0.01	0.00	0.00	0.01
TC-21-5-4-3-2	0.24	0.00	0.14	0.01	0.00	0.15	0.01	0.01	0.00	0.00
TC-21-5-5-3-2	0.30	0.01	0.23	0.01	0.00	0.21	0.00	0.01	0.01	0.00
TC-21-5-1-3-3	0.22	0.01	0.14	0.01	0.01	0.14	0.00	0.01	0.01	0.01
TC-21-5-2-3-3	0.43	0.00	0.34	0.01	0.01	0.29	0.01	0.01	0.00	0.01
TC-21-5-3-3-3	0.42	0.01	0.35	0.01	0.00	0.32	0.01	0.01	0.01	0.01
TC-21-5-4-3-3	0.42	0.00	0.32	0.01	0.01	0.28	0.01	0.01	0.00	0.00
TC-21-5-5-3-3	0.56	0.00	0.35	0.01	0.01	0.36	0.00	0.01	0.00	0.01
TC-21-5-1-4-1	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
TC-21-5-2-4-1	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
TC-21-5-3-4-1	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
TC-21-5-4-4-1	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
TC-21-5-5-4-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TC-21-5-1-4-2	0.19	0.00	0.07	0.01	0.01	0.08	0.01	0.00	0.01	0.00
TC-21-5-2-4-2	0.17	0.01	0.17	0.01	0.01	0.19	0.00	0.01	0.01	0.01
TC-21-5-3-4-2	0.21	0.01	0.16	0.01	0.01	0.13	0.00	0.01	0.00	0.01
TC-21-5-4-4-2	0.29	0.01	0.16	0.01	0.01	0.16	0.02	0.01	0.01	0.01
TC-21-5-5-4-2	0.28	0.01	0.22	0.01	0.01	0.27	0.00	0.01	0.00	0.01
TC-21-5-1-4-3	0.27	0.01	0.14	0.01	0.01	0.16	0.02	0.01	0.01	0.01
TC-21-5-2-4-3	0.36	0.00	0.29	0.01	0.01	0.28	0.01	0.00	0.00	0.01
TC-21-5-3-4-3	0.53	0.01	0.41	0.01	0.00	0.30	0.01	0.01	0.02	0.02
TC-21-5-4-4-3	0.50	0.01	0.30	0.01	0.00	0.31	0.01	0.01	0.01	0.00
TC-21-5-5-4-3	0.41	0.01	0.35	0.01	0.01	0.36	0.01	0.01	0.02	0.02
TC-21-5-1-5-1	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01
TC-21-5-2-5-1	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01
TC-21-5-3-5-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
TC-21-5-4-5-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
TC-21-5-5-5-1	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01
TC-21-5-1-5-2	0.25	0.00	0.08	0.01	0.00	0.09	0.01	0.01	0.02	0.00
TC-21-5-2-5-2	0.16	0.01	0.17	0.01	0.00	0.15	0.01	0.01	0.02	0.01
TC-21-5-3-5-2	0.20	0.00	0.17	0.00	0.01	0.14	0.01	0.01	0.02	0.01
TC-21-5-4-5-2	0.38	0.01	0.20	0.02	0.01	0.17	0.00	0.01	0.01	0.01
TC-21-5-5-5-2	0.35	0.01	0.27	0.01	0.00	0.22	0.01	0.01	0.01	0.01
TC-21-5-1-5-3	0.40	0.01	0.23	0.01	0.01	0.20	0.01	0.02	0.02	0.02
TC-21-5-2-5-3	0.31	0.01	0.29	0.01	0.01	0.25	0.02	0.02	0.00	0.01
TC-21-5-3-5-3	0.78	0.01	0.48	0.01	0.01	0.40	0.00	0.00	0.01	0.02
TC-21-5-4-5-3	0.71	0.00	0.27	0.02	0.01	0.30	0.01	0.02	0.01	0.02
TC-21-5-5-5-3	0.60	0.01	0.55	0.01	0.01	0.44	0.02	0.02	0.01	0.01

Table A.2: Time consumation (s) for node-disjointness on TC-21-5 instances.

	VND with									
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TC-21-5-1-3-1	116	116	116	116	116	116	116	116	116	116
TC-21-5-2-3-1	174	174	174	174	174	174	174	174	174	174
TC-21-5-3-3-1	114	114	114	114	102	102	102	102	102	102
TC-21-5-4-3-1	168	168	168	168	168	168	168	168	168	168
TC-21-5-5-3-1	157	157	157	157	162	162	162	162	162	162
TC-21-5-1-3-2	235	235	235	235	235	235	235	235	235	235
TC-21-5-2-3-2	327	260	329	286	260	352	260	260	260	260
TC-21-5-3-3-2	196	252	196	188	252	196	188	188	188	188
TC-21-5-4-3-2	336	269	336	304	269	336	304	304	304	304
TC-21-5-5-3-2	262	262	326	262	262	326	262	262	262	262
TC-21-5-1-3-3	366	372	375	376	372	366	376	376	376	376
TC-21-5-2-3-3	537	483	537	472	483	537	489	489	489	489
TC-21-5-3-3-3	336	413	397	336	413	417	336	336	336	336
TC-21-5-4-3-3	439	437	439	473	437	439	473	473	473	473
TC-21-5-5-3-3	529	485	498	443	485	498	443	443	443	443
TC-21-5-1-4-1	116	116	116	116	116	116	116	116	116	116
TC-21-5-2-4-1	174	174	174	174	174	174	174	174	174	174
TC-21-5-3-4-1	114	114	114	114	102	102	102	102	102	102
TC-21-5-4-4-1	168	168	168	168	168	168	168	168	168	168
TC-21-5-5-4-1	157	157	157	157	162	162	162	162	162	162
TC-21-5-1-4-2	238	235	235	235	235	235	235	235	235	235
TC-21-5-2-4-2	333	260	339	260	260	333	260	260	260	260
TC-21-5-3-4-2	230	197	196	188	197	196	188	188	188	188
TC-21-5-4-4-2	306	269	306	304	269	306	304	304	304	304
TC-21-5-5-4-2	316	262	311	262	262	394	262	262	262	262
TC-21-5-1-4-3	351	372	375	376	372	351	376	376	376	376
TC-21-5-2-4-3	531	483	533	472	483	533	489	489	489	489
TC-21-5-3-4-3	413	413	336	336	413	441	336	336	336	336
TC-21-5-4-4-3	465	437	439	473	437	519	473	473	473	473
TC-21-5-5-4-3	476	485	444	443	485	485	443	443	443	443
TC-21-5-1-5-1	116	116	116	116	116	116	116	116	116	116
TC-21-5-2-5-1	174	174	174	174	174	174	174	174	174	174
TC-21-5-3-5-1	114	114	114	114	102	102	102	102	102	102
TC-21-5-4-5-1	168	168	168	168	168	168	168	168	168	168
TC-21-5-5-5-1	157	157	157	157	162	162	162	162	162	162
TC-21-5-1-5-2	221	235	235	235	235	235	235	235	235	235
TC-21-5-2-5-2	339	260	303	260	260	361	260	260	260	260
TC-21-5-3-5-2	238	197	196	188	197	196	188	188	188	188
TC-21-5-4-5-2	306	269	306	304	269	306	304	304	304	304
TC-21-5-5-5-2	358	262	268	262	262	358	262	262	262	262
TC-21-5-1-5-3	337	372	375	376	372	351	376	376	376	376
TC-21-5-2-5-3	488	483	488	472	483	488	489	489	489	489
TC-21-5-3-5-3	362	413	334	336	413	366	336	336	336	336
TC-21-5-4-5-3	496	437	484	473	437	498	473	473	473	473
TC-21-5-5-5-3	484	485	444	443	485	487	443	443	443	443

Table A.3: Results for node-disjointness on TC-21-5 instances.

	VND with									
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TC-21-5-1-3-1	0.03	0.03	0.03	0.03	0.01	0.01	0.02	0.02	0.01	0.02
TC-21-5-2-3-1	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.02
TC-21-5-3-3-1	0.03	0.03	0.03	0.03	0.02	0.03	0.01	0.02	0.02	0.01
TC-21-5-4-3-1	0.03	0.02	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.02
TC-21-5-5-3-1	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
TC-21-5-1-3-2	0.27	0.10	0.17	0.06	0.11	0.21	0.04	0.04	0.04	0.03
TC-21-5-2-3-2	0.47	0.12	0.36	0.13	0.13	0.35	0.07	0.07	0.07	0.07
TC-21-5-3-3-2	0.41	0.06	0.36	0.08	0.06	0.29	0.11	0.11	0.11	0.11
TC-21-5-4-3-2	0.28	0.09	0.20	0.11	0.08	0.20	0.09	0.09	0.08	0.09
TC-21-5-5-3-2	0.38	0.11	0.28	0.09	0.10	0.24	0.07	0.07	0.07	0.07
TC-21-5-1-3-3	0.36	0.11	0.31	0.10	0.11	0.34	0.05	0.05	0.05	0.06
TC-21-5-2-3-3	0.52	0.20	0.41	0.16	0.20	0.39	0.11	0.12	0.12	0.12
TC-21-5-3-3-3	0.62	0.08	0.64	0.09	0.09	0.55	0.09	0.09	0.10	0.09
TC-21-5-4-3-3	0.56	0.11	0.49	0.15	0.11	0.42	0.12	0.11	0.11	0.12
TC-21-5-5-3-3	0.63	0.11	0.44	0.15	0.11	0.41	0.09	0.10	0.09	0.10
TC-21-5-1-4-1	0.03	0.03	0.03	0.03	0.02	0.03	0.02	0.02	0.02	0.02
TC-21-5-2-4-1	0.03	0.03	0.03	0.03	0.01	0.01	0.01	0.02	0.02	0.02
TC-21-5-3-4-1	0.03	0.03	0.03	0.03	0.03	0.03	0.01	0.02	0.02	0.02
TC-21-5-4-4-1	0.03	0.03	0.03	0.03	0.02	0.03	0.02	0.02	0.02	0.02
TC-21-5-5-4-1	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.04	0.03
TC-21-5-1-4-2	0.31	0.13	0.18	0.07	0.12	0.21	0.05	0.05	0.05	0.05
TC-21-5-2-4-2	0.33	0.14	0.27	0.16	0.13	0.33	0.07	0.08	0.08	0.07
TC-21-5-3-4-2	0.39	0.12	0.33	0.09	0.11	0.29	0.13	0.13	0.13	0.12
TC-21-5-4-4-2	0.36	0.10	0.27	0.13	0.10	0.23	0.10	0.09	0.11	0.11
TC-21-5-5-4-2	0.36	0.12	0.30	0.11	0.12	0.35	0.08	0.08	0.08	0.08
TC-21-5-1-4-3	0.51	0.12	0.35	0.12	0.13	0.43	0.06	0.06	0.06	0.06
TC-21-5-2-4-3	0.48	0.23	0.42	0.18	0.23	0.42	0.13	0.14	0.14	0.13
TC-21-5-3-4-3	0.73	0.10	0.63	0.09	0.11	0.52	0.12	0.12	0.10	0.10
TC-21-5-4-4-3	0.61	0.13	0.53	0.17	0.13	0.47	0.14	0.13	0.13	0.13
TC-21-5-5-4-3	0.52	0.12	0.56	0.17	0.13	0.43	0.12	0.12	0.11	0.11
TC-21-5-1-5-1	0.04	0.04	0.04	0.04	0.02	0.02	0.02	0.02	0.02	0.03
TC-21-5-2-5-1	0.04	0.03	0.02	0.03	0.01	0.02	0.02	0.02	0.02	0.02
TC-21-5-3-5-1	0.03	0.04	0.03	0.04	0.02	0.02	0.02	0.02	0.03	0.03
TC-21-5-4-5-1	0.05	0.03	0.04	0.04	0.02	0.02	0.03	0.03	0.03	0.02
TC-21-5-5-5-1	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.03
TC-21-5-1-5-2	0.41	0.13	0.20	0.08	0.14	0.22	0.06	0.05	0.04	0.05
TC-21-5-2-5-2	0.30	0.15	0.41	0.19	0.16	0.27	0.07	0.08	0.08	0.08
TC-21-5-3-5-2	0.33	0.13	0.35	0.11	0.12	0.31	0.15	0.14	0.15	0.15
TC-21-5-4-5-2	0.48	0.11	0.31	0.15	0.10	0.28	0.11	0.11	0.12	0.12
TC-21-5-5-5-2	0.40	0.12	0.43	0.12	0.13	0.31	0.09	0.09	0.10	0.10
TC-21-5-1-5-3	0.72	0.15	0.44	0.13	0.15	0.57	0.09	0.08	0.08	0.07
TC-21-5-2-5-3	0.46	0.25	0.49	0.21	0.26	0.43	0.15	0.16	0.16	0.16
TC-21-5-3-5-3	1.01	0.12	0.81	0.05	0.12	0.65	0.13	0.12	0.13	0.07
TC-21-5-4-5-3	0.92	0.14	0.55	0.20	0.15	0.50	0.15	0.16	0.16	0.16
TC-21-5-5-5-3	0.66	0.14	0.77	0.19	0.14	0.51	0.13	0.13	0.13	0.13

Table A.4: Time consumation (s) for node-disjointness on TC-21-5 instances.

	MSVND with											
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TC-21-5-1-3-1	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00
TC-21-5-2-3-1	166.00	0.00	166.00	0.00	166.00	0.00	166.00	0.00	166.00	0.00	166.00	0.00
TC-21-5-3-3-1	102.80	3.04	102.40	2.19	102.40	2.19	102.40	2.19	102.40	2.19	102.40	2.19
TC-21-5-4-3-1	163.67	1.73	163.83	1.90	163.83	1.90	164.33	2.25	163.50	1.53	163.67	1.73
TC-21-5-5-3-1	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00
TC-21-5-1-3-2	235.00	0.00	235.00	0.00	235.00	0.00	235.00	0.00	235.00	0.00	235.00	0.00
TC-21-5-2-3-2	260.00	0.00	260.00	0.00	260.00	0.00	260.00	0.00	260.00	0.00	260.00	0.00
TC-21-5-3-3-2	252.00	0.00	252.00	0.00	252.00	0.00	188.00	0.00	188.00	0.00	188.00	0.00
TC-21-5-4-3-2	269.00	0.00	269.00	0.00	269.00	0.00	269.27	1.46	269.00	0.00	269.73	4.02
TC-21-5-5-3-2	262.00	0.00	262.00	0.00	262.00	0.00	262.00	0.00	262.00	0.00	262.00	0.00
TC-21-5-1-3-3	372.00	0.00	372.00	0.00	372.00	0.00	348.13	10.02	347.87	6.85	344.53	4.02
TC-21-5-2-3-3	483.00	0.00	483.00	0.00	483.00	0.00	475.00	3.81	474.00	0.00	474.50	2.74
TC-21-5-3-3-3	413.00	0.00	413.00	0.00	413.00	0.00	336.00	0.00	336.00	0.00	336.00	0.00
TC-21-5-4-3-3	437.00	0.00	437.00	0.00	437.00	0.00	437.20	1.10	437.00	0.00	437.00	0.00
TC-21-5-5-3-3	485.00	0.00	485.00	0.00	485.00	0.00	439.00	0.00	439.00	0.00	439.00	0.00
TC-21-5-1-4-1	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00
TC-21-5-2-4-1	166.00	0.00	166.00	0.00	166.00	0.00	166.00	0.00	166.00	0.00	166.00	0.00
TC-21-5-3-4-1	102.00	0.00	102.00	0.00	102.40	2.19	102.00	0.00	102.40	2.19	102.00	0.00
TC-21-5-4-4-1	163.83	1.90	163.67	1.73	163.83	1.90	164.17	2.15	163.50	1.53	164.33	2.25
TC-21-5-5-4-1	157.17	0.91	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00
TC-21-5-1-4-2	235.00	0.00	235.00	0.00	235.00	0.00	235.00	0.00	235.00	0.00	235.00	0.00
TC-21-5-2-4-2	260.00	0.00	260.00	0.00	260.00	0.00	260.00	0.00	260.00	0.00	260.00	0.00
TC-21-5-3-4-2	197.00	0.00	197.00	0.00	197.00	0.00	188.00	0.00	188.00	0.00	188.00	0.00
TC-21-5-4-4-2	269.00	0.00	269.00	0.00	269.00	0.00	269.00	0.00	269.00	0.00	269.00	0.00
TC-21-5-5-4-2	262.00	0.00	262.00	0.00	262.00	0.00	262.00	0.00	262.00	0.00	262.00	0.00
TC-21-5-1-4-3	372.00	0.00	372.00	0.00	372.00	0.00	345.87	8.49	347.67	8.70	346.97	9.19
TC-21-5-2-4-3	483.00	0.00	483.00	0.00	483.00	0.00	474.50	2.74	474.00	0.00	474.50	2.74
TC-21-5-3-4-3	413.00	0.00	413.00	0.00	413.00	0.00	331.23	5.54	331.97	5.39	332.70	5.13
TC-21-5-4-4-3	437.00	0.00	437.00	0.00	437.00	0.00	438.20	6.57	437.20	1.10	437.20	1.10
TC-21-5-5-4-3	485.00	0.00	485.00	0.00	485.00	0.00	439.00	0.00	439.00	0.00	439.13	0.73
TC-21-5-1-5-1	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00
TC-21-5-2-5-1	166.00	0.00	166.00	0.00	166.00	0.00	166.27	1.46	166.00	0.00	166.00	0.00
TC-21-5-3-5-1	102.80	3.04	102.00	0.00	102.40	2.19	102.40	2.19	102.00	0.00	102.00	0.00
TC-21-5-4-5-1	164.00	2.03	163.67	1.73	163.83	1.90	164.00	2.03	164.47	3.12	163.83	1.90
TC-21-5-5-5-1	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00
TC-21-5-1-5-2	235.00	0.00	235.00	0.00	235.00	0.00	235.00	0.00	235.00	0.00	235.00	0.00
TC-21-5-2-5-2	260.00	0.00	260.00	0.00	260.00	0.00	260.00	0.00	260.00	0.00	260.00	0.00
TC-21-5-3-5-2	197.00	0.00	197.00	0.00	197.00	0.00	188.00	0.00	188.00	0.00	188.00	0.00
TC-21-5-4-5-2	269.00	0.00	269.00	0.00	269.00	0.00	269.00	0.00	269.00	0.00	269.00	0.00
TC-21-5-5-5-2	262.00	0.00	262.00	0.00	262.00	0.00	262.00	0.00	262.00	0.00	262.00	0.00
TC-21-5-1-5-3	372.00	0.00	372.00	0.00	372.00	0.00	345.17	4.75	346.63	7.32	347.43	9.34
TC-21-5-2-5-3	483.00	0.00	483.00	0.00	483.00	0.00	474.50	2.74	474.50	2.74	475.00	3.81
TC-21-5-3-5-3	413.00	0.00	413.00	0.00	413.00	0.00	332.33	5.27	331.97	5.39	331.97	5.39
TC-21-5-4-5-3	437.00	0.00	437.00	0.00	437.00	0.00	438.20	6.57	437.00	0.00	437.53	2.10
TC-21-5-5-5-3	485.00	0.00	485.00	0.00	485.00	0.00	439.00	0.00	439.00	0.00	439.00	0.00

Table A.5: Results for node-disjointness on TC-21-5 instances.

	MSVND with											
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TC-21-5-1-3-1	0.21	0.02	0.21	0.02	0.21	0.02	0.21	0.01	0.22	0.02	0.22	0.02
TC-21-5-2-3-1	0.20	0.02	0.19	0.03	0.20	0.02	0.20	0.03	0.19	0.02	0.19	0.02
TC-21-5-3-3-1	0.18	0.01	0.18	0.01	0.18	0.01	0.18	0.01	0.18	0.01	0.18	0.01
TC-21-5-4-3-1	0.17	0.01	0.18	0.01	0.17	0.01	0.17	0.01	0.17	0.01	0.17	0.01
TC-21-5-5-3-1	0.19	0.02	0.20	0.02	0.20	0.02	0.20	0.02	0.20	0.02	0.20	0.02
TC-21-5-1-3-2	1.00	0.01	1.00	0.00	1.00	0.00	0.54	0.05	0.56	0.06	0.52	0.06
TC-21-5-2-3-2	1.11	0.01	1.11	0.01	1.11	0.01	0.84	0.05	0.84	0.04	0.84	0.05
TC-21-5-3-3-2	0.58	0.01	0.58	0.01	0.58	0.01	0.69	0.05	0.69	0.06	0.68	0.07
TC-21-5-4-3-2	0.81	0.01	0.81	0.00	0.81	0.01	0.83	0.03	0.82	0.03	0.83	0.03
TC-21-5-5-3-2	0.99	0.01	0.99	0.01	0.99	0.01	0.73	0.03	0.72	0.03	0.72	0.03
TC-21-5-1-3-3	0.99	0.01	0.99	0.00	0.99	0.01	0.75	0.09	0.78	0.08	0.78	0.09
TC-21-5-2-3-3	1.80	0.01	1.78	0.01	1.78	0.01	1.02	0.02	1.02	0.03	1.02	0.03
TC-21-5-3-3-3	0.83	0.01	0.83	0.00	0.83	0.01	0.93	0.05	0.91	0.09	0.93	0.05
TC-21-5-4-3-3	1.02	0.01	1.02	0.01	1.02	0.01	1.00	0.06	1.01	0.04	1.01	0.05
TC-21-5-5-3-3	1.07	0.15	1.02	0.05	1.02	0.01	0.89	0.07	0.88	0.05	0.89	0.05
TC-21-5-1-4-1	0.36	0.06	0.25	0.03	0.25	0.02	0.25	0.02	0.25	0.02	0.25	0.02
TC-21-5-2-4-1	0.22	0.02	0.24	0.03	0.22	0.02	0.24	0.02	0.23	0.02	0.23	0.02
TC-21-5-3-4-1	0.21	0.02	0.21	0.02	0.20	0.01	0.21	0.01	0.21	0.01	0.22	0.01
TC-21-5-4-4-1	0.20	0.01	0.20	0.01	0.20	0.01	0.21	0.01	0.20	0.02	0.21	0.01
TC-21-5-5-4-1	0.23	0.02	0.23	0.03	0.23	0.02	0.23	0.02	0.23	0.02	0.24	0.02
TC-21-5-1-4-2	1.14	0.01	1.14	0.01	1.14	0.00	0.60	0.06	0.61	0.08	0.63	0.07
TC-21-5-2-4-2	1.25	0.01	1.26	0.00	1.26	0.01	1.06	0.06	1.08	0.06	1.04	0.06
TC-21-5-3-4-2	1.05	0.01	1.05	0.01	1.05	0.01	0.76	0.06	0.76	0.05	0.75	0.08
TC-21-5-4-4-2	0.91	0.01	0.91	0.01	0.92	0.01	1.29	0.25	0.96	0.03	0.96	0.03
TC-21-5-5-4-2	1.12	0.01	1.12	0.00	1.13	0.00	0.84	0.04	0.83	0.03	0.84	0.04
TC-21-5-1-4-3	1.14	0.01	1.14	0.01	1.14	0.01	0.88	0.08	0.92	0.08	0.91	0.12
TC-21-5-2-4-3	2.04	0.01	2.04	0.01	2.04	0.01	1.18	0.04	1.19	0.03	1.19	0.04
TC-21-5-3-4-3	1.06	0.20	0.97	0.10	1.04	0.16	1.10	0.09	1.12	0.11	1.09	0.08
TC-21-5-4-4-3	1.17	0.01	1.17	0.00	1.17	0.00	1.17	0.06	1.17	0.05	1.16	0.06
TC-21-5-5-4-3	1.19	0.07	1.16	0.02	1.24	0.21	1.02	0.07	1.01	0.08	1.02	0.08
TC-21-5-1-5-1	0.28	0.02	0.29	0.02	0.28	0.02	0.28	0.02	0.29	0.02	0.28	0.02
TC-21-5-2-5-1	0.26	0.02	0.26	0.02	0.27	0.02	0.26	0.03	0.27	0.03	0.26	0.02
TC-21-5-3-5-1	0.24	0.02	0.24	0.02	0.24	0.02	0.24	0.02	0.25	0.03	0.28	0.06
TC-21-5-4-5-1	0.24	0.02	0.23	0.01	0.23	0.01	0.23	0.01	0.23	0.01	0.23	0.01
TC-21-5-5-5-1	0.26	0.02	0.26	0.02	0.26	0.03	0.26	0.02	0.26	0.02	0.27	0.02
TC-21-5-1-5-2	1.28	0.00	1.28	0.01	1.28	0.00	0.69	0.08	0.70	0.08	0.70	0.09
TC-21-5-2-5-2	1.41	0.01	1.42	0.01	1.42	0.01	1.20	0.07	1.20	0.08	1.22	0.08
TC-21-5-3-5-2	1.18	0.01	1.18	0.00	1.18	0.01	0.87	0.08	0.87	0.06	0.84	0.09
TC-21-5-4-5-2	1.02	0.01	1.03	0.01	1.03	0.01	1.08	0.04	1.09	0.03	1.09	0.03
TC-21-5-5-5-2	1.26	0.01	1.26	0.01	1.26	0.01	0.96	0.05	0.95	0.05	0.96	0.04
TC-21-5-1-5-3	1.59	0.27	1.32	0.03	1.29	0.01	1.03	0.09	1.03	0.09	1.00	0.08
TC-21-5-2-5-3	2.30	0.01	2.30	0.00	2.30	0.01	1.33	0.04	1.34	0.03	1.35	0.03
TC-21-5-3-5-3	1.06	0.02	1.06	0.01	1.06	0.01	1.22	0.10	1.29	0.10	1.24	0.10
TC-21-5-4-5-3	1.38	0.18	1.34	0.03	1.41	0.24	1.30	0.07	1.29	0.06	1.31	0.06
TC-21-5-5-5-3	1.32	0.01	1.32	0.01	1.32	0.00	1.18	0.08	1.18	0.06	1.18	0.07

Table A.6: Time consumation (s) for node-disjointness on TC-21-5 instances.

	GRASP											
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TC-21-5-1-3-1	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00
TC-21-5-2-3-1	174.00	0.00	174.00	0.00	174.00	0.00	174.00	0.00	174.00	0.00	174.00	0.00
TC-21-5-3-3-1	114.00	0.00	114.00	0.00	114.00	0.00	114.00	0.00	114.00	0.00	114.00	0.00
TC-21-5-4-3-1	168.00	0.00	168.00	0.00	168.00	0.00	168.00	0.00	168.00	0.00	168.00	0.00
TC-21-5-5-3-1	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00
TC-21-5-1-3-2	237.13	8.12	242.30	13.64	258.10	28.48	275.07	50.06	255.23	30.30	275.23	39.34
TC-21-5-2-3-2	334.20	3.66	337.13	19.93	332.83	23.48	331.67	41.67	367.17	50.22	373.23	56.41
TC-21-5-3-3-2	196.00	0.00	207.43	25.25	221.63	29.72	233.13	40.60	251.47	57.97	250.90	71.92
TC-21-5-4-3-2	336.00	0.00	319.43	20.80	313.63	33.70	331.70	42.82	355.63	66.80	368.67	81.55
TC-21-5-5-3-2	262.00	0.00	282.87	25.64	277.27	27.30	319.67	66.57	332.07	50.09	356.60	58.81
TC-21-5-1-3-3	365.27	0.98	377.00	26.64	401.60	37.43	390.20	30.91	410.47	68.23	410.70	44.46
TC-21-5-2-3-3	518.53	13.70	505.20	26.54	496.67	37.25	500.93	45.28	525.30	47.54	560.20	69.95
TC-21-5-3-3-3	387.33	36.92	392.70	40.81	385.30	44.34	384.47	44.79	405.87	65.02	427.97	78.99
TC-21-5-4-3-3	439.00	0.00	450.77	20.28	484.83	37.16	491.23	44.89	510.80	59.42	525.20	71.18
TC-21-5-5-3-3	515.13	16.69	480.07	27.87	480.37	31.13	506.93	50.28	501.27	51.85	509.60	58.87
TC-21-5-1-4-1	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00
TC-21-5-2-4-1	174.00	0.00	174.00	0.00	174.00	0.00	174.00	0.00	174.00	0.00	174.00	0.00
TC-21-5-3-4-1	114.00	0.00	114.00	0.00	114.00	0.00	114.00	0.00	114.00	0.00	114.00	0.00
TC-21-5-4-4-1	168.00	0.00	168.00	0.00	168.00	0.00	168.00	0.00	168.00	0.00	168.00	0.00
TC-21-5-5-4-1	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00
TC-21-5-1-4-2	236.70	1.51	239.07	20.72	270.53	31.95	272.87	44.43	271.80	47.43	277.90	44.91
TC-21-5-2-4-2	309.73	35.12	300.37	33.01	305.57	34.81	351.57	60.18	364.80	69.21	384.33	72.61
TC-21-5-3-4-2	230.00	0.00	207.03	18.33	226.63	33.17	243.23	43.70	254.73	52.23	248.43	51.06
TC-21-5-4-4-2	306.00	0.00	298.30	18.75	323.13	34.61	346.43	58.09	375.40	91.44	363.53	62.66
TC-21-5-5-4-2	316.00	0.00	287.57	42.65	275.77	20.72	330.97	51.98	359.17	67.46	369.80	75.24
TC-21-5-1-4-3	348.67	3.36	367.43	19.85	397.03	38.69	440.47	65.10	421.67	63.94	411.63	62.03
TC-21-5-2-4-3	474.93	33.89	462.40	24.91	489.30	39.86	519.87	45.82	540.30	66.54	549.40	81.23
TC-21-5-3-4-3	390.90	25.70	383.57	27.70	379.97	44.60	400.77	53.20	435.87	98.92	434.10	76.31
TC-21-5-4-4-3	465.00	0.00	478.63	33.25	492.67	32.10	513.53	49.87	544.00	86.57	573.37	81.84
TC-21-5-5-4-3	476.00	0.00	479.67	32.19	469.17	26.25	498.70	63.06	522.63	75.22	515.23	74.34
TC-21-5-1-5-1	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00
TC-21-5-2-5-1	174.00	0.00	174.00	0.00	174.00	0.00	174.00	0.00	174.00	0.00	174.00	0.00
TC-21-5-3-5-1	114.00	0.00	114.00	0.00	114.00	0.00	114.00	0.00	114.00	0.00	114.00	0.00
TC-21-5-4-5-1	168.00	0.00	168.00	0.00	168.00	0.00	168.00	0.00	168.00	0.00	168.00	0.00
TC-21-5-5-5-1	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00
TC-21-5-1-5-2	228.47	7.10	239.33	20.58	249.70	26.84	277.10	50.43	287.17	51.42	272.07	59.61
TC-21-5-2-5-2	326.07	16.77	293.70	21.53	311.93	44.83	335.67	47.58	353.73	77.36	351.63	61.22
TC-21-5-3-5-2	238.00	0.00	217.87	21.47	212.67	27.83	244.30	48.24	235.90	46.86	252.50	72.49
TC-21-5-4-5-2	306.00	0.00	301.03	25.81	304.53	24.76	333.93	61.28	341.10	68.01	373.90	91.72
TC-21-5-5-5-2	346.10	29.71	303.87	43.34	292.93	30.04	323.60	63.24	319.73	66.31	348.93	75.59
TC-21-5-1-5-3	345.67	19.71	369.63	26.75	398.30	39.06	426.53	60.42	440.60	74.22	425.53	66.69
TC-21-5-2-5-3	467.43	16.41	454.90	21.75	496.70	55.22	535.80	65.74	558.83	104.26	556.33	79.99
TC-21-5-3-5-3	380.00	22.74	367.97	26.94	370.87	51.93	425.60	76.54	431.07	71.13	442.63	79.67
TC-21-5-4-5-3	473.50	22.88	478.20	36.43	486.17	34.00	520.27	72.90	529.80	75.77	547.73	79.86
TC-21-5-5-5-3	484.00	0.00	472.30	35.20	459.27	26.73	505.90	75.55	506.63	53.22	534.87	65.99

Table A.7: Results for node-disjointness on TC-21-5 instances.

	GRASP											
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TC-21-5-1-3-1	0.03	0.01	0.03	0.01	0.03	0.00	0.03	0.01	0.03	0.00	0.03	0.00
TC-21-5-2-3-1	0.02	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.02	0.01
TC-21-5-3-3-1	0.03	0.00	0.03	0.00	0.03	0.01	0.04	0.01	0.04	0.01	0.04	0.01
TC-21-5-4-3-1	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.01	0.03	0.01
TC-21-5-5-3-1	0.02	0.00	0.02	0.00	0.02	0.01	0.02	0.00	0.02	0.01	0.02	0.01
TC-21-5-1-3-2	0.29	0.02	0.23	0.05	0.30	0.10	0.26	0.07	0.30	0.09	0.30	0.07
TC-21-5-2-3-2	0.47	0.01	0.41	0.06	0.29	0.08	0.27	0.09	0.31	0.08	0.27	0.08
TC-21-5-3-3-2	0.47	0.05	0.51	0.11	0.34	0.09	0.32	0.09	0.31	0.10	0.30	0.09
TC-21-5-4-3-2	0.31	0.01	0.37	0.09	0.32	0.10	0.32	0.12	0.30	0.07	0.27	0.07
TC-21-5-5-3-2	0.38	0.02	0.38	0.07	0.33	0.10	0.26	0.08	0.28	0.08	0.27	0.06
TC-21-5-1-3-3	0.39	0.03	0.38	0.07	0.40	0.08	0.42	0.08	0.41	0.09	0.45	0.09
TC-21-5-2-3-3	0.57	0.04	0.57	0.08	0.46	0.09	0.43	0.11	0.43	0.07	0.45	0.09
TC-21-5-3-3-3	0.59	0.04	0.66	0.07	0.54	0.12	0.47	0.11	0.47	0.11	0.44	0.09
TC-21-5-4-3-3	0.52	0.05	0.58	0.11	0.59	0.14	0.44	0.09	0.45	0.09	0.46	0.12
TC-21-5-5-3-3	0.55	0.04	0.58	0.08	0.61	0.08	0.41	0.08	0.46	0.08	0.43	0.08
TC-21-5-1-4-1	0.03	0.01	0.03	0.00	0.03	0.00	0.03	0.00	0.04	0.01	0.03	0.01
TC-21-5-2-4-1	0.03	0.01	0.03	0.01	0.03	0.01	0.03	0.01	0.03	0.00	0.03	0.00
TC-21-5-3-4-1	0.03	0.01	0.04	0.01	0.03	0.01	0.03	0.01	0.03	0.01	0.03	0.00
TC-21-5-4-4-1	0.03	0.01	0.03	0.01	0.03	0.00	0.03	0.00	0.03	0.01	0.03	0.00
TC-21-5-5-4-1	0.03	0.01	0.03	0.01	0.03	0.01	0.03	0.00	0.03	0.00	0.03	0.00
TC-21-5-1-4-2	0.31	0.03	0.28	0.08	0.25	0.07	0.29	0.09	0.29	0.08	0.28	0.08
TC-21-5-2-4-2	0.37	0.05	0.40	0.07	0.31	0.09	0.29	0.09	0.29	0.07	0.29	0.08
TC-21-5-3-4-2	0.38	0.02	0.37	0.09	0.33	0.13	0.30	0.11	0.30	0.06	0.30	0.10
TC-21-5-4-4-2	0.40	0.01	0.45	0.11	0.37	0.14	0.29	0.08	0.30	0.09	0.28	0.08
TC-21-5-5-4-2	0.38	0.01	0.44	0.07	0.32	0.07	0.27	0.09	0.27	0.10	0.31	0.10
TC-21-5-1-4-3	0.54	0.04	0.47	0.07	0.52	0.16	0.46	0.10	0.51	0.13	0.53	0.14
TC-21-5-2-4-3	0.62	0.08	0.60	0.09	0.52	0.14	0.48	0.12	0.47	0.11	0.46	0.09
TC-21-5-3-4-3	0.76	0.02	0.83	0.17	0.82	0.23	0.56	0.18	0.48	0.11	0.53	0.11
TC-21-5-4-4-3	0.61	0.06	0.69	0.13	0.64	0.18	0.58	0.15	0.52	0.14	0.46	0.10
TC-21-5-5-4-3	0.54	0.02	0.67	0.09	0.64	0.13	0.49	0.11	0.52	0.14	0.54	0.14
TC-21-5-1-5-1	0.04	0.00	0.04	0.01	0.04	0.01	0.04	0.01	0.04	0.00	0.04	0.01
TC-21-5-2-5-1	0.03	0.00	0.03	0.01	0.03	0.00	0.03	0.01	0.03	0.00	0.03	0.01
TC-21-5-3-5-1	0.04	0.00	0.04	0.01	0.04	0.00	0.04	0.00	0.04	0.01	0.04	0.00
TC-21-5-4-5-1	0.04	0.01	0.04	0.01	0.04	0.01	0.04	0.00	0.04	0.00	0.04	0.00
TC-21-5-5-5-1	0.03	0.00	0.03	0.01	0.03	0.01	0.03	0.01	0.03	0.00	0.03	0.01
TC-21-5-1-5-2	0.40	0.05	0.33	0.08	0.33	0.13	0.33	0.10	0.32	0.09	0.36	0.10
TC-21-5-2-5-2	0.34	0.02	0.36	0.05	0.36	0.10	0.32	0.12	0.34	0.11	0.33	0.11
TC-21-5-3-5-2	0.39	0.03	0.41	0.08	0.39	0.13	0.32	0.11	0.33	0.08	0.35	0.09
TC-21-5-4-5-2	0.53	0.02	0.62	0.22	0.44	0.18	0.38	0.13	0.33	0.11	0.35	0.11
TC-21-5-5-5-2	0.49	0.08	0.53	0.10	0.43	0.14	0.33	0.11	0.38	0.12	0.36	0.12
TC-21-5-1-5-3	0.66	0.12	0.57	0.13	0.56	0.19	0.63	0.22	0.63	0.18	0.60	0.17
TC-21-5-2-5-3	0.59	0.06	0.69	0.16	0.61	0.13	0.60	0.23	0.67	0.33	0.61	0.19
TC-21-5-3-5-3	1.01	0.06	1.06	0.30	0.78	0.23	0.59	0.20	0.61	0.19	0.58	0.15
TC-21-5-4-5-3	0.96	0.08	1.08	0.28	0.99	0.51	0.66	0.22	0.65	0.14	0.61	0.19
TC-21-5-5-5-3	0.68	0.05	0.83	0.20	0.85	0.20	0.58	0.14	0.59	0.11	0.53	0.17

Table A.8: Time consumation (s) for node-disjointness on TC-21-5 instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TC-21-10-1-3-1	389	389	389	389	252	252	252	252	252	252
TC-21-10-2-3-1	365	365	365	365	263	263	263	263	263	263
TC-21-10-3-3-1	445	445	445	445	278	278	278	278	278	278
TC-21-10-4-3-1	425	425	425	425	256	256	256	256	256	256
TC-21-10-5-3-1	405	405	405	405	273	273	273	273	273	273
TC-21-10-1-3-2	477	978	633	683	978	553	536	536	536	536
TC-21-10-2-3-2	488	836	607	719	836	547	596	596	596	596
TC-21-10-3-3-2	541	919	690	801	919	541	507	507	507	507
TC-21-10-4-3-2	600	1057	696	738	1057	644	574	574	574	574
TC-21-10-5-3-2	521	1037	689	693	1037	689	567	567	567	567
TC-21-10-1-3-3	755	1413	990	990	1413	804	834	834	834	834
TC-21-10-2-3-3	754	1335	915	1000	1335	809	917	917	917	917
TC-21-10-3-3-3	826	1341	1032	1106	1341	831	795	795	795	795
TC-21-10-4-3-3	808	1655	1012	1108	1655	894	940	940	940	940
TC-21-10-5-3-3	821	1697	946	997	1697	902	817	817	817	817
TC-21-10-1-4-1	389	389	389	389	252	252	252	252	252	252
TC-21-10-2-4-1	365	365	365	365	263	263	263	263	263	263
TC-21-10-3-4-1	445	445	445	445	278	278	278	278	278	278
TC-21-10-4-4-1	425	425	425	425	256	256	256	256	256	256
TC-21-10-5-4-1	405	405	405	405	273	273	273	273	273	273
TC-21-10-1-4-2	450	978	526	683	978	464	536	536	536	536
TC-21-10-2-4-2	478	836	568	719	836	546	596	596	596	596
TC-21-10-3-4-2	507	919	643	801	919	509	507	507	507	507
TC-21-10-4-4-2	547	1057	617	738	1057	547	574	574	574	574
TC-21-10-5-4-2	478	1037	613	693	1037	604	567	567	567	567
TC-21-10-1-4-3	646	1413	894	990	1413	717	834	834	834	834
TC-21-10-2-4-3	656	1335	836	1000	1335	732	917	917	917	917
TC-21-10-3-4-3	718	1341	1000	1106	1341	779	795	795	795	795
TC-21-10-4-4-3	737	1655	1056	1108	1655	819	940	940	940	940
TC-21-10-5-4-3	709	1697	923	997	1697	871	817	817	817	817
TC-21-10-1-5-1	389	389	389	389	252	252	252	252	252	252
TC-21-10-2-5-1	365	365	365	365	263	263	263	263	263	263
TC-21-10-3-5-1	445	445	445	445	278	278	278	278	278	278
TC-21-10-4-5-1	425	425	425	425	256	256	256	256	256	256
TC-21-10-5-5-1	405	405	405	405	273	273	273	273	273	273
TC-21-10-1-5-2	420	978	554	683	978	434	536	536	536	536
TC-21-10-2-5-2	486	836	574	719	836	520	596	596	596	596
TC-21-10-3-5-2	497	919	541	801	919	479	507	507	507	507
TC-21-10-4-5-2	495	1057	625	738	1057	535	574	574	574	574
TC-21-10-5-5-2	450	1037	601	693	1037	570	567	567	567	567
TC-21-10-1-5-3	632	1413	894	990	1413	737	834	834	834	834
TC-21-10-2-5-3	628	1335	808	1000	1335	704	917	917	917	917
TC-21-10-3-5-3	632	1341	931	1106	1341	690	795	795	795	795
TC-21-10-4-5-3	714	1655	938	1108	1655	791	940	940	940	940
TC-21-10-5-5-3	666	1697	887	997	1697	807	817	817	817	817

Table A.9: Results for node-disjointness on TC-21-10 instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TC-21-10-1-3-1	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
TC-21-10-2-3-1	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00
TC-21-10-3-3-1	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.00
TC-21-10-4-3-1	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00
TC-21-10-5-3-1	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.00
TC-21-10-1-3-2	0.51	0.01	0.28	0.02	0.02	0.37	0.01	0.01	0.01	0.02
TC-21-10-2-3-2	0.48	0.01	0.26	0.02	0.02	0.27	0.02	0.02	0.02	0.02
TC-21-10-3-3-2	0.50	0.02	0.37	0.02	0.02	0.30	0.01	0.01	0.02	0.01
TC-21-10-4-3-2	0.31	0.01	0.33	0.02	0.02	0.33	0.02	0.01	0.01	0.02
TC-21-10-5-3-2	0.53	0.02	0.36	0.02	0.02	0.48	0.02	0.01	0.01	0.02
TC-21-10-1-3-3	0.66	0.01	0.47	0.02	0.02	0.52	0.03	0.02	0.01	0.02
TC-21-10-2-3-3	0.65	0.01	0.52	0.02	0.02	0.49	0.03	0.02	0.01	0.02
TC-21-10-3-3-3	0.73	0.02	0.68	0.03	0.02	0.57	0.03	0.02	0.01	0.02
TC-21-10-4-3-3	0.47	0.02	0.58	0.03	0.01	0.48	0.02	0.02	0.02	0.02
TC-21-10-5-3-3	1.01	0.03	0.85	0.03	0.03	0.81	0.04	0.03	0.03	0.03
TC-21-10-1-4-1	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00
TC-21-10-2-4-1	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.00
TC-21-10-3-4-1	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.01
TC-21-10-4-4-1	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01
TC-21-10-5-4-1	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01
TC-21-10-1-4-2	0.63	0.02	0.26	0.02	0.02	0.29	0.02	0.01	0.01	0.02
TC-21-10-2-4-2	0.56	0.02	0.24	0.02	0.02	0.26	0.02	0.02	0.03	0.02
TC-21-10-3-4-2	0.37	0.02	0.31	0.02	0.02	0.28	0.02	0.01	0.01	0.01
TC-21-10-4-4-2	0.28	0.02	0.32	0.01	0.01	0.27	0.02	0.02	0.03	0.03
TC-21-10-5-4-2	0.55	0.01	0.37	0.02	0.02	0.43	0.02	0.02	0.03	0.02
TC-21-10-1-4-3	0.88	0.02	0.55	0.03	0.02	0.52	0.03	0.03	0.03	0.03
TC-21-10-2-4-3	0.75	0.02	0.47	0.02	0.02	0.40	0.03	0.03	0.03	0.03
TC-21-10-3-4-3	0.87	0.02	0.68	0.02	0.02	0.56	0.03	0.03	0.03	0.02
TC-21-10-4-4-3	0.58	0.02	0.59	0.02	0.02	0.51	0.02	0.02	0.02	0.02
TC-21-10-5-4-3	0.77	0.02	0.60	0.03	0.02	0.61	0.03	0.03	0.02	0.02
TC-21-10-1-5-1	0.01	0.01	0.01	0.02	0.00	0.01	0.01	0.01	0.01	0.02
TC-21-10-2-5-1	0.01	0.01	0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.00
TC-21-10-3-5-1	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.02
TC-21-10-4-5-1	0.01	0.01	0.01	0.02	0.01	0.01	0.00	0.01	0.01	0.01
TC-21-10-5-5-1	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.02
TC-21-10-1-5-2	0.89	0.02	0.30	0.02	0.02	0.26	0.03	0.02	0.02	0.02
TC-21-10-2-5-2	0.72	0.02	0.26	0.02	0.01	0.26	0.02	0.03	0.02	0.03
TC-21-10-3-5-2	0.44	0.03	0.35	0.03	0.02	0.26	0.02	0.02	0.02	0.02
TC-21-10-4-5-2	0.33	0.01	0.36	0.03	0.02	0.28	0.02	0.02	0.02	0.03
TC-21-10-5-5-2	0.69	0.01	0.47	0.02	0.02	0.46	0.03	0.02	0.03	0.02
TC-21-10-1-5-3	1.40	0.02	0.80	0.03	0.02	0.72	0.03	0.03	0.03	0.04
TC-21-10-2-5-3	0.95	0.02	0.54	0.03	0.02	0.48	0.03	0.04	0.03	0.04
TC-21-10-3-5-3	1.38	0.02	0.95	0.03	0.02	0.56	0.03	0.03	0.03	0.03
TC-21-10-4-5-3	0.66	0.02	0.58	0.03	0.01	0.45	0.03	0.03	0.03	0.04
TC-21-10-5-5-3	1.10	0.02	0.88	0.03	0.02	0.71	0.02	0.03	0.03	0.03

Table A.10: Time consumation (s) for node-disjointness on TC-21-10 instances.

	VND with									
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TC-21-10-1-3-1	238	238	238	238	238	238	238	238	238	238
TC-21-10-2-3-1	236	236	236	236	228	228	228	228	228	228
TC-21-10-3-3-1	230	230	230	230	236	236	236	236	236	236
TC-21-10-4-3-1	241	241	241	241	242	242	242	242	242	242
TC-21-10-5-3-1	230	230	230	230	238	238	238	238	238	238
TC-21-10-1-3-2	448	416	463	463	416	514	405	405	405	405
TC-21-10-2-3-2	483	445	525	425	445	495	501	501	501	501
TC-21-10-3-3-2	509	479	479	497	479	532	447	447	447	447
TC-21-10-4-3-2	561	476	500	435	476	516	457	457	457	457
TC-21-10-5-3-2	521	429	521	429	429	505	465	465	465	465
TC-21-10-1-3-3	708	668	706	655	668	705	660	660	660	660
TC-21-10-2-3-3	754	633	675	681	633	708	644	644	644	644
TC-21-10-3-3-3	727	701	753	698	701	770	711	711	711	711
TC-21-10-4-3-3	744	769	745	669	769	722	672	672	672	672
TC-21-10-5-3-3	788	678	825	695	678	833	678	678	678	678
TC-21-10-1-4-1	238	238	238	238	238	238	238	238	238	238
TC-21-10-2-4-1	236	236	236	236	228	228	228	228	228	228
TC-21-10-3-4-1	236	236	236	236	236	236	236	236	236	236
TC-21-10-4-4-1	241	241	241	241	242	242	242	242	242	242
TC-21-10-5-4-1	230	230	230	230	238	238	238	238	238	238
TC-21-10-1-4-2	422	405	427	403	405	427	377	377	377	377
TC-21-10-2-4-2	421	408	463	390	408	468	456	456	456	456
TC-21-10-3-4-2	492	478	466	491	478	488	433	433	433	433
TC-21-10-4-4-2	480	399	501	391	399	508	403	403	403	403
TC-21-10-5-4-2	467	415	467	415	415	467	407	407	407	407
TC-21-10-1-4-3	622	668	579	632	668	633	618	618	618	618
TC-21-10-2-4-3	656	633	656	670	633	656	644	644	644	644
TC-21-10-3-4-3	693	689	764	653	689	705	669	669	669	669
TC-21-10-4-4-3	687	713	719	669	713	719	640	640	640	640
TC-21-10-5-4-3	694	678	741	695	678	740	678	678	678	678
TC-21-10-1-5-1	238	238	238	238	238	238	238	238	238	238
TC-21-10-2-5-1	236	236	236	236	228	228	228	228	228	228
TC-21-10-3-5-1	236	236	236	236	236	236	236	236	236	236
TC-21-10-4-5-1	241	241	241	241	242	242	242	242	242	242
TC-21-10-5-5-1	230	230	230	230	238	238	238	238	238	238
TC-21-10-1-5-2	414	363	392	389	363	392	363	363	363	363
TC-21-10-2-5-2	413	378	413	390	378	427	416	416	416	416
TC-21-10-3-5-2	394	459	475	477	459	455	419	419	419	419
TC-21-10-4-5-2	396	399	393	391	399	396	403	403	403	403
TC-21-10-5-5-2	442	415	401	415	415	475	407	407	407	407
TC-21-10-1-5-3	579	668	576	632	668	636	618	618	618	618
TC-21-10-2-5-3	611	633	599	650	633	621	644	644	644	644
TC-21-10-3-5-3	613	667	615	653	667	638	658	658	658	658
TC-21-10-4-5-3	624	673	653	669	673	713	640	640	640	640
TC-21-10-5-5-3	624	678	690	695	678	732	678	678	678	678

Table A.11: Results for node-disjointness on TC-21-10 instances.

	VND with									
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TC-21-10-1-3-1	0.13	0.12	0.11	0.12	0.04	0.04	0.05	0.05	0.04	0.03
TC-21-10-2-3-1	0.14	0.15	0.15	0.15	0.08	0.08	0.08	0.07	0.08	0.08
TC-21-10-3-3-1	0.12	0.13	0.12	0.12	0.10	0.10	0.10	0.10	0.11	0.09
TC-21-10-4-3-1	0.14	0.14	0.14	0.15	0.08	0.08	0.08	0.08	0.08	0.08
TC-21-10-5-3-1	0.16	0.16	0.16	0.15	0.09	0.09	0.09	0.09	0.10	0.09
TC-21-10-1-3-2	0.73	0.36	0.61	0.31	0.36	0.59	0.28	0.28	0.29	0.29
TC-21-10-2-3-2	0.58	0.32	0.48	0.50	0.32	0.41	0.20	0.20	0.21	0.20
TC-21-10-3-3-2	0.70	0.35	0.74	0.34	0.36	0.42	0.16	0.16	0.16	0.16
TC-21-10-4-3-2	0.48	0.39	0.61	0.43	0.38	0.56	0.22	0.22	0.22	0.21
TC-21-10-5-3-2	0.57	0.38	0.47	0.39	0.38	0.76	0.24	0.24	0.24	0.24
TC-21-10-1-3-3	0.96	0.49	0.95	0.59	0.49	0.81	0.29	0.29	0.29	0.30
TC-21-10-2-3-3	0.71	0.53	0.92	0.57	0.54	0.76	0.36	0.36	0.36	0.37
TC-21-10-3-3-3	1.23	0.57	1.28	0.46	0.58	0.80	0.26	0.27	0.27	0.27
TC-21-10-4-3-3	0.76	0.58	0.96	0.60	0.58	0.91	0.50	0.50	0.50	0.50
TC-21-10-5-3-3	1.49	0.95	1.38	0.91	0.95	1.45	0.53	0.53	0.52	0.53
TC-21-10-1-4-1	0.14	0.14	0.15	0.14	0.05	0.05	0.04	0.05	0.05	0.05
TC-21-10-2-4-1	0.17	0.17	0.17	0.18	0.09	0.08	0.09	0.09	0.10	0.10
TC-21-10-3-4-1	0.16	0.16	0.15	0.15	0.10	0.10	0.10	0.11	0.11	0.10
TC-21-10-4-4-1	0.17	0.18	0.16	0.17	0.09	0.09	0.09	0.09	0.09	0.09
TC-21-10-5-4-1	0.18	0.18	0.19	0.18	0.10	0.10	0.10	0.10	0.10	0.11
TC-21-10-1-4-2	0.92	0.47	0.75	0.51	0.47	0.65	0.38	0.38	0.38	0.38
TC-21-10-2-4-2	0.80	0.47	0.60	0.65	0.48	0.58	0.35	0.35	0.35	0.35
TC-21-10-3-4-2	0.52	0.37	0.76	0.44	0.37	0.46	0.23	0.24	0.23	0.24
TC-21-10-4-4-2	0.54	0.60	0.67	0.59	0.59	0.43	0.33	0.33	0.33	0.32
TC-21-10-5-4-2	0.73	0.49	0.82	0.50	0.49	0.87	0.36	0.36	0.35	0.35
TC-21-10-1-4-3	1.06	0.57	1.25	0.79	0.58	0.89	0.45	0.45	0.46	0.45
TC-21-10-2-4-3	0.82	0.62	0.79	0.74	0.61	0.58	0.42	0.42	0.42	0.41
TC-21-10-3-4-3	1.10	0.69	1.29	0.58	0.68	0.95	0.34	0.34	0.34	0.35
TC-21-10-4-4-3	0.88	0.80	1.29	0.69	0.78	1.00	0.65	0.64	0.64	0.64
TC-21-10-5-4-3	0.90	0.69	1.12	0.67	0.70	1.04	0.40	0.39	0.40	0.39
TC-21-10-1-5-1	0.17	0.17	0.15	0.16	0.05	0.06	0.06	0.06	0.06	0.06
TC-21-10-2-5-1	0.19	0.19	0.19	0.19	0.11	0.11	0.11	0.10	0.10	0.10
TC-21-10-3-5-1	0.14	0.14	0.15	0.14	0.11	0.12	0.12	0.12	0.11	0.12
TC-21-10-4-5-1	0.19	0.19	0.20	0.19	0.10	0.11	0.10	0.10	0.11	0.11
TC-21-10-5-5-1	0.20	0.31	0.23	0.23	0.18	0.15	0.12	0.12	0.12	0.12
TC-21-10-1-5-2	1.07	0.63	0.79	0.63	0.63	0.58	0.49	0.48	0.48	0.48
TC-21-10-2-5-2	1.10	0.56	0.83	0.73	0.56	0.54	0.40	0.39	0.39	0.39
TC-21-10-3-5-2	1.03	0.46	0.71	0.50	0.46	0.55	0.32	0.32	0.32	0.32
TC-21-10-4-5-2	0.90	0.67	1.08	0.66	0.67	0.95	0.38	0.38	0.38	0.37
TC-21-10-5-5-2	0.82	0.54	1.18	0.55	0.54	0.89	0.39	0.39	0.39	0.39
TC-21-10-1-5-3	1.79	0.64	1.74	0.89	0.64	1.09	0.50	0.51	0.51	0.50
TC-21-10-2-5-3	1.19	0.68	1.15	0.82	0.69	0.91	0.48	0.47	0.48	0.48
TC-21-10-3-5-3	1.78	0.72	1.77	0.65	0.73	1.00	0.43	0.42	0.42	0.42
TC-21-10-4-5-3	1.14	0.89	1.34	0.79	0.88	1.02	0.72	0.73	0.71	0.73
TC-21-10-5-5-3	1.55	0.78	1.63	0.74	0.77	0.95	0.43	0.44	0.44	0.44

Table A.12: Time consumation (s) for node-disjointness on TC-21-10 instances.

	MSVND with											
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TC-21-10-1-3-1	220.33	4.76	220.33	5.61	220.00	4.07	219.80	5.62	218.40	4.28	219.20	4.51
TC-21-10-2-3-1	228.53	2.03	228.80	2.44	228.27	1.46	228.00	0.00	228.00	0.00	228.53	2.03
TC-21-10-3-3-1	222.63	8.22	219.97	8.43	218.93	9.18	221.97	7.69	224.07	7.40	221.70	7.54
TC-21-10-4-3-1	231.33	5.55	231.63	6.09	230.53	5.16	233.87	5.47	232.23	6.70	231.60	5.05
TC-21-10-5-3-1	228.57	1.50	228.53	0.82	228.90	1.67	228.77	1.55	228.97	1.65	228.67	1.42
TC-21-10-1-3-2	416.00	0.00	416.00	0.00	416.00	0.00	426.47	11.40	425.70	9.06	426.33	11.51
TC-21-10-2-3-2	445.00	0.00	445.00	0.00	445.00	0.00	431.40	9.46	432.47	12.46	430.13	10.24
TC-21-10-3-3-2	479.00	0.00	479.00	0.00	479.00	0.00	421.77	7.33	421.37	9.66	421.23	9.53
TC-21-10-4-3-2	476.00	0.00	476.00	0.00	476.00	0.00	444.03	6.78	446.03	6.04	446.90	9.20
TC-21-10-5-3-2	429.00	0.00	429.00	0.00	429.00	0.00	429.10	5.44	429.77	4.52	429.23	3.06
TC-21-10-1-3-3	668.00	0.00	668.00	0.00	668.00	0.00	621.67	13.60	613.40	13.58	616.50	11.96
TC-21-10-2-3-3	633.00	0.00	633.00	0.00	633.00	0.00	615.17	14.97	610.73	18.01	615.07	15.94
TC-21-10-3-3-3	701.00	0.00	701.00	0.00	701.00	0.00	662.37	18.39	661.47	13.82	657.33	11.35
TC-21-10-4-3-3	769.00	0.00	769.00	0.00	769.00	0.00	659.97	5.41	659.53	4.80	659.40	5.31
TC-21-10-5-3-3	678.00	0.00	678.00	0.00	678.00	0.00	659.70	12.82	664.00	13.10	658.53	12.45
TC-21-10-1-4-1	223.27	4.53	222.13	3.44	221.27	5.47	223.53	4.80	222.93	4.57	222.93	5.03
TC-21-10-2-4-1	228.80	2.44	228.80	2.44	228.00	0.00	229.07	2.77	228.27	1.46	228.80	2.44
TC-21-10-3-4-1	225.87	6.13	222.00	7.29	222.17	5.53	222.47	6.04	223.93	5.40	224.27	6.53
TC-21-10-4-4-1	234.80	5.96	233.30	5.13	232.43	5.23	234.60	6.41	232.40	5.40	232.13	5.44
TC-21-10-5-4-1	228.40	0.62	228.80	0.89	228.40	0.56	228.47	0.68	228.37	0.81	228.23	0.57
TC-21-10-1-4-2	405.00	0.00	405.00	0.00	405.00	0.00	383.73	7.08	384.23	7.37	385.10	7.09
TC-21-10-2-4-2	408.00	0.00	408.00	0.00	408.00	0.00	397.17	12.98	399.53	12.68	402.60	11.78
TC-21-10-3-4-2	478.00	0.00	478.00	0.00	478.00	0.00	400.47	5.70	400.90	6.97	398.83	8.12
TC-21-10-4-4-2	399.00	0.00	399.00	0.00	399.00	0.00	390.43	4.09	390.13	3.70	389.67	3.58
TC-21-10-5-4-2	415.00	0.00	415.00	0.00	415.00	0.00	408.03	3.93	407.47	3.85	407.07	3.53
TC-21-10-1-4-3	668.00	0.00	668.00	0.00	668.00	0.00	581.47	16.64	579.57	15.24	583.37	16.33
TC-21-10-2-4-3	633.00	0.00	633.00	0.00	633.00	0.00	585.83	17.06	594.97	11.72	591.23	13.81
TC-21-10-3-4-3	689.00	0.00	689.00	0.00	689.00	0.00	620.33	12.21	615.87	15.43	613.83	14.79
TC-21-10-4-4-3	713.00	0.00	713.00	0.00	713.00	0.00	635.13	14.81	631.23	13.21	631.33	15.60
TC-21-10-5-4-3	678.00	0.00	678.00	0.00	678.00	0.00	657.03	14.04	656.00	13.24	655.53	11.87
TC-21-10-1-5-1	221.87	4.67	222.13	3.44	223.47	5.12	221.33	3.84	222.93	5.38	221.60	4.77
TC-21-10-2-5-1	228.27	1.46	228.27	1.46	228.53	2.03	228.27	1.46	228.27	1.46	228.27	1.46
TC-21-10-3-5-1	223.10	7.10	223.90	5.41	225.77	4.96	225.43	4.92	223.10	4.89	222.97	6.67
TC-21-10-4-5-1	231.43	5.78	231.43	5.56	232.10	6.00	231.40	5.82	231.80	5.55	232.87	6.22
TC-21-10-5-5-1	228.47	0.73	228.33	0.71	228.60	0.72	228.53	0.78	228.37	0.67	228.67	0.80
TC-21-10-1-5-2	363.00	0.00	363.00	0.00	363.00	0.00	358.80	8.81	362.60	9.82	361.90	6.91
TC-21-10-2-5-2	378.00	0.00	378.00	0.00	378.00	0.00	374.80	10.40	375.50	8.62	377.90	7.24
TC-21-10-3-5-2	459.00	0.00	459.00	0.00	459.00	0.00	365.70	11.27	366.63	11.09	367.30	10.07
TC-21-10-4-5-2	399.00	0.00	399.00	0.00	399.00	0.00	380.83	9.99	379.17	9.53	380.87	8.72
TC-21-10-5-5-2	415.00	0.00	415.00	0.00	415.00	0.00	404.27	6.45	402.87	6.04	402.53	5.88
TC-21-10-1-5-3	668.00	0.00	668.00	0.00	668.00	0.00	578.40	13.59	577.93	14.12	581.93	13.38
TC-21-10-2-5-3	633.00	0.00	633.00	0.00	633.00	0.00	584.00	12.79	592.37	11.98	588.10	11.31
TC-21-10-3-5-3	667.00	0.00	667.00	0.00	667.00	0.00	598.57	14.11	600.27	15.13	600.80	13.62
TC-21-10-4-5-3	673.00	0.00	673.00	0.00	673.00	0.00	633.53	11.88	634.93	12.15	634.10	11.16
TC-21-10-5-5-3	678.00	0.00	678.00	0.00	678.00	0.00	658.23	14.75	652.73	12.32	656.73	10.85

Table A.13: Results for node-disjointness on TC-21-10 instances.

	MSVND with											
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TC-21-10-1-3-1	0.74	0.08	0.70	0.06	0.70	0.07	0.74	0.07	0.76	0.06	0.74	0.06
TC-21-10-2-3-1	0.78	0.04	0.79	0.05	0.80	0.06	0.81	0.05	0.81	0.05	0.81	0.05
TC-21-10-3-3-1	0.71	0.06	0.73	0.08	0.72	0.07	0.72	0.09	0.69	0.07	0.72	0.07
TC-21-10-4-3-1	0.76	0.05	0.76	0.05	0.76	0.05	0.77	0.04	0.77	0.05	0.78	0.04
TC-21-10-5-3-1	0.79	0.07	0.80	0.05	0.81	0.06	0.82	0.06	0.79	0.07	0.82	0.05
TC-21-10-1-3-2	3.40	0.29	3.32	0.02	3.36	0.14	2.25	0.13	2.16	0.15	2.17	0.14
TC-21-10-2-3-2	2.92	0.01	2.91	0.01	2.91	0.01	2.05	0.12	2.08	0.14	2.10	0.11
TC-21-10-3-3-2	3.27	0.01	3.27	0.01	3.27	0.01	1.78	0.12	1.75	0.15	1.79	0.12
TC-21-10-4-3-2	3.47	0.02	3.47	0.00	3.53	0.27	1.98	0.11	1.90	0.15	1.92	0.13
TC-21-10-5-3-2	3.43	0.03	3.42	0.01	3.48	0.29	2.37	0.21	2.33	0.15	2.35	0.18
TC-21-10-1-3-3	4.46	0.01	4.46	0.01	4.45	0.01	3.70	0.31	3.59	0.29	3.57	0.25
TC-21-10-2-3-3	4.82	0.01	4.81	0.01	4.81	0.01	3.40	0.22	3.41	0.26	3.36	0.27
TC-21-10-3-3-3	5.17	0.01	5.17	0.01	5.17	0.01	2.90	0.22	2.86	0.26	2.92	0.28
TC-21-10-4-3-3	5.28	0.01	5.28	0.01	5.28	0.01	3.41	0.21	3.40	0.21	3.44	0.27
TC-21-10-5-3-3	6.34	0.92	6.28	1.05	5.46	0.05	4.07	0.80	4.08	0.69	4.22	0.66
TC-21-10-1-4-1	0.76	0.04	0.75	0.06	0.75	0.05	0.74	0.06	0.76	0.06	0.74	0.05
TC-21-10-2-4-1	0.85	0.05	0.85	0.06	0.85	0.05	0.85	0.06	0.84	0.05	0.84	0.06
TC-21-10-3-4-1	0.71	0.06	0.95	0.21	0.81	0.18	0.71	0.05	0.72	0.05	0.72	0.06
TC-21-10-4-4-1	0.76	0.06	0.77	0.06	0.79	0.05	0.80	0.05	0.79	0.05	0.80	0.05
TC-21-10-5-4-1	0.89	0.06	0.92	0.08	0.88	0.08	0.92	0.06	0.92	0.05	0.90	0.05
TC-21-10-1-4-2	4.23	0.01	4.23	0.01	4.23	0.01	3.48	0.20	3.45	0.22	3.49	0.20
TC-21-10-2-4-2	4.41	0.54	4.33	0.44	4.27	0.21	2.95	0.15	2.96	0.14	2.86	0.18
TC-21-10-3-4-2	3.33	0.20	3.43	0.43	3.28	0.01	2.65	0.13	2.73	0.26	2.67	0.21
TC-21-10-4-4-2	5.38	0.01	5.38	0.01	5.38	0.01	3.16	0.15	3.13	0.20	3.13	0.18
TC-21-10-5-4-2	4.36	0.02	4.36	0.02	4.98	0.87	4.27	0.65	3.21	0.24	3.18	0.21
TC-21-10-1-4-3	5.17	0.01	5.17	0.01	5.16	0.01	5.21	0.36	5.13	0.34	5.22	0.40
TC-21-10-2-4-3	5.54	0.01	5.53	0.01	5.60	0.30	4.73	0.30	4.73	0.26	4.83	0.41
TC-21-10-3-4-3	6.25	0.01	6.25	0.01	6.25	0.01	4.08	0.23	4.15	0.29	4.15	0.33
TC-21-10-4-4-3	7.19	0.02	7.23	0.05	7.20	0.02	4.30	0.32	4.30	0.38	4.24	0.34
TC-21-10-5-4-3	6.27	0.02	6.27	0.03	6.26	0.01	4.38	0.26	4.31	0.35	4.36	0.23
TC-21-10-1-5-1	0.83	0.07	0.84	0.09	0.86	0.07	0.99	0.22	0.86	0.07	0.85	0.06
TC-21-10-2-5-1	0.96	0.09	0.93	0.06	0.97	0.06	0.96	0.05	0.97	0.06	0.94	0.05
TC-21-10-3-5-1	0.80	0.07	0.79	0.06	0.78	0.06	0.80	0.06	0.79	0.06	0.81	0.06
TC-21-10-4-5-1	0.92	0.15	1.05	0.19	0.88	0.07	0.87	0.06	0.85	0.07	0.85	0.05
TC-21-10-5-5-1	1.32	0.23	1.02	0.07	1.01	0.08	0.99	0.05	1.02	0.08	1.01	0.08
TC-21-10-1-5-2	5.68	0.01	5.68	0.01	5.68	0.01	4.67	0.23	4.66	0.23	4.60	0.20
TC-21-10-2-5-2	5.07	0.04	5.11	0.02	5.09	0.04	3.72	0.25	3.76	0.19	3.74	0.19
TC-21-10-3-5-2	4.16	0.01	4.16	0.01	4.16	0.01	3.34	0.17	3.29	0.17	3.34	0.24
TC-21-10-4-5-2	6.04	0.02	6.04	0.02	6.04	0.02	3.60	0.17	3.70	0.19	3.61	0.22
TC-21-10-5-5-2	4.86	0.01	4.86	0.01	4.86	0.01	3.74	0.26	3.80	0.24	3.68	0.23
TC-21-10-1-5-3	5.82	0.01	5.82	0.01	5.82	0.01	5.89	0.47	5.87	0.41	5.94	0.48
TC-21-10-2-5-3	6.16	0.01	6.16	0.01	6.16	0.01	5.37	0.35	5.33	0.31	5.41	0.31
TC-21-10-3-5-3	6.58	0.01	6.59	0.01	6.58	0.01	4.97	0.34	4.95	0.35	4.96	0.32
TC-21-10-4-5-3	8.06	0.01	8.06	0.01	8.22	0.56	4.83	0.47	4.92	0.36	4.84	0.33
TC-21-10-5-5-3	7.06	0.01	7.06	0.01	7.08	0.05	4.91	0.36	4.87	0.29	4.91	0.28

Table A.14: Time consumation (s) for node-disjointness on TC-21-10 instances.

	GRASP											
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TC-21-10-1-3-1	238.00	0.00	238.00	0.00	238.00	0.00	238.00	0.00	238.00	0.00	238.00	0.00
TC-21-10-2-3-1	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00
TC-21-10-3-3-1	230.00	0.00	230.00	0.00	230.00	0.00	230.00	0.00	230.00	0.00	230.00	0.00
TC-21-10-4-3-1	241.00	0.00	241.00	0.00	241.00	0.00	241.00	0.00	241.00	0.00	241.00	0.00
TC-21-10-5-3-1	230.00	0.00	230.00	0.00	230.00	0.00	230.00	0.00	230.00	0.00	230.00	0.00
TC-21-10-1-3-2	445.73	2.45	474.73	29.84	526.03	45.72	602.57	59.20	620.33	76.05	615.00	78.32
TC-21-10-2-3-2	489.87	10.92	498.70	16.25	513.67	42.22	583.03	63.54	643.30	80.15	636.23	83.38
TC-21-10-3-3-2	485.83	13.25	498.47	32.98	529.80	43.90	569.00	55.78	630.33	77.55	659.57	92.47
TC-21-10-4-3-2	535.40	10.38	509.07	29.80	543.07	47.05	610.63	66.44	673.67	107.02	661.57	69.45
TC-21-10-5-3-2	508.23	20.57	493.20	20.44	522.20	27.73	579.40	63.49	641.30	80.64	649.13	74.65
TC-21-10-1-3-3	692.27	17.59	719.23	35.15	748.17	55.11	843.63	79.63	933.53	94.75	924.33	88.85
TC-21-10-2-3-3	721.33	21.13	715.23	45.40	754.60	59.85	825.30	76.15	904.07	105.06	932.63	93.18
TC-21-10-3-3-3	711.43	18.35	743.20	53.54	782.07	67.36	862.13	69.32	911.10	97.44	961.67	115.87
TC-21-10-4-3-3	757.03	23.90	734.90	40.17	786.23	46.11	912.23	113.72	1004.93	84.50	1009.03	122.30
TC-21-10-5-3-3	747.23	32.23	759.53	41.96	782.90	51.50	876.07	87.23	909.07	74.88	986.30	113.15
TC-21-10-1-4-1	238.00	0.00	238.00	0.00	238.00	0.00	238.00	0.00	238.00	0.00	238.00	0.00
TC-21-10-2-4-1	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00
TC-21-10-3-4-1	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00
TC-21-10-4-4-1	241.00	0.00	241.00	0.00	241.00	0.00	241.00	0.00	241.00	0.00	241.00	0.00
TC-21-10-5-4-1	230.00	0.00	230.00	0.00	230.00	0.00	230.00	0.00	230.00	0.00	230.00	0.00
TC-21-10-1-4-2	415.03	10.73	439.93	28.62	537.50	62.25	621.50	70.34	639.43	82.50	662.03	66.23
TC-21-10-2-4-2	433.47	11.09	453.87	21.02	515.23	48.35	572.00	74.86	632.93	85.15	695.03	96.77
TC-21-10-3-4-2	469.07	23.50	467.60	26.93	534.00	55.16	606.30	69.47	626.73	82.04	678.77	82.40
TC-21-10-4-4-2	491.20	10.66	469.50	23.65	525.23	52.31	627.73	83.99	703.77	112.75	712.70	126.00
TC-21-10-5-4-2	469.00	2.88	471.77	30.51	496.43	35.74	600.03	83.15	718.57	98.13	733.07	107.23
TC-21-10-1-4-3	593.83	13.87	665.73	33.99	747.30	77.34	869.83	93.76	941.80	110.12	955.73	126.04
TC-21-10-2-4-3	654.10	10.36	654.37	37.50	773.57	72.82	871.07	91.37	941.10	123.66	971.17	133.69
TC-21-10-3-4-3	672.40	23.99	684.37	34.09	766.17	67.73	878.37	86.60	933.03	119.54	976.63	136.91
TC-21-10-4-4-3	677.90	9.86	694.97	37.32	775.93	60.99	895.63	94.09	1018.03	118.95	1027.63	115.32
TC-21-10-5-4-3	694.00	0.00	701.87	41.21	736.50	46.84	856.13	63.75	1002.47	101.23	1064.33	133.48
TC-21-10-1-5-1	238.00	0.00	238.00	0.00	238.00	0.00	238.00	0.00	238.00	0.00	238.00	0.00
TC-21-10-2-5-1	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00
TC-21-10-3-5-1	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00
TC-21-10-4-5-1	241.00	0.00	241.00	0.00	241.00	0.00	241.00	0.00	241.00	0.00	241.00	0.00
TC-21-10-5-5-1	230.00	0.00	230.00	0.00	230.00	0.00	230.00	0.00	230.00	0.00	230.00	0.00
TC-21-10-1-5-2	395.53	17.79	420.37	35.98	508.10	56.03	601.87	93.26	628.70	84.44	681.27	92.10
TC-21-10-2-5-2	413.00	0.00	424.23	24.31	503.63	63.52	575.37	64.01	660.03	86.84	674.97	132.06
TC-21-10-3-5-2	417.33	39.42	444.50	28.80	533.27	51.18	581.70	68.66	624.87	95.45	678.40	132.93
TC-21-10-4-5-2	396.00	0.00	437.60	28.11	529.27	61.62	599.33	75.88	674.00	105.84	691.77	85.48
TC-21-10-5-5-2	422.37	20.07	448.87	35.42	480.60	50.20	590.50	66.92	689.27	122.54	718.07	91.96
TC-21-10-1-5-3	577.90	1.47	659.90	46.08	757.97	78.55	907.80	108.31	938.00	122.07	998.27	141.29
TC-21-10-2-5-3	610.00	3.81	627.03	37.05	737.97	65.15	852.90	78.88	912.60	87.69	970.77	122.74
TC-21-10-3-5-3	613.47	0.51	640.77	33.59	755.17	79.04	886.90	101.30	964.40	122.06	954.13	135.04
TC-21-10-4-5-3	650.23	21.97	679.70	26.57	796.27	46.72	887.13	88.31	1025.30	135.26	1049.17	146.98
TC-21-10-5-5-3	624.00	0.00	669.10	36.69	706.83	46.88	868.33	86.47	968.20	80.17	1032.30	132.78

Table A.15: Results for node-disjointness on TC-21-10 instances.

	GRASP											
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TC-21-10-1-3-1	0.12	0.00	0.12	0.01	0.12	0.00	0.12	0.01	0.12	0.01	0.12	0.00
TC-21-10-2-3-1	0.15	0.00	0.15	0.01	0.15	0.00	0.15	0.00	0.15	0.01	0.15	0.01
TC-21-10-3-3-1	0.12	0.00	0.12	0.01	0.12	0.00	0.12	0.01	0.12	0.00	0.12	0.01
TC-21-10-4-3-1	0.17	0.04	0.16	0.03	0.15	0.01	0.15	0.01	0.15	0.00	0.15	0.01
TC-21-10-5-3-1	0.16	0.01	0.16	0.00	0.16	0.01	0.16	0.00	0.16	0.00	0.16	0.01
TC-21-10-1-3-2	0.76	0.03	0.79	0.10	0.70	0.14	0.81	0.28	0.81	0.22	0.68	0.13
TC-21-10-2-3-2	0.62	0.05	0.71	0.14	0.65	0.17	0.61	0.10	0.67	0.15	0.71	0.14
TC-21-10-3-3-2	0.82	0.04	0.88	0.12	0.72	0.16	0.72	0.16	0.63	0.14	0.69	0.14
TC-21-10-4-3-2	0.47	0.04	0.56	0.10	0.59	0.13	0.70	0.11	0.68	0.19	0.66	0.12
TC-21-10-5-3-2	0.64	0.04	0.70	0.08	0.73	0.13	0.64	0.12	0.67	0.12	0.67	0.18
TC-21-10-1-3-3	0.89	0.06	1.06	0.14	1.11	0.24	1.01	0.18	0.98	0.15	0.99	0.21
TC-21-10-2-3-3	0.83	0.05	1.04	0.19	1.01	0.21	1.01	0.24	0.99	0.18	1.01	0.19
TC-21-10-3-3-3	1.01	0.10	1.14	0.16	1.18	0.24	1.05	0.24	0.99	0.20	0.99	0.21
TC-21-10-4-3-3	0.76	0.03	0.88	0.16	0.98	0.19	1.04	0.21	1.01	0.14	0.98	0.24
TC-21-10-5-3-3	1.14	0.18	1.06	0.15	1.18	0.13	0.99	0.26	1.00	0.16	0.97	0.20
TC-21-10-1-4-1	0.14	0.00	0.14	0.01	0.14	0.01	0.14	0.01	0.14	0.00	0.14	0.01
TC-21-10-2-4-1	0.17	0.01	0.17	0.00	0.17	0.01	0.17	0.01	0.17	0.01	0.17	0.00
TC-21-10-3-4-1	0.16	0.00	0.16	0.00	0.16	0.00	0.16	0.00	0.17	0.03	0.16	0.01
TC-21-10-4-4-1	0.17	0.01	0.17	0.00	0.17	0.00	0.17	0.01	0.17	0.00	0.17	0.00
TC-21-10-5-4-1	0.19	0.01	0.18	0.00	0.18	0.00	0.19	0.01	0.18	0.01	0.18	0.01
TC-21-10-1-4-2	1.05	0.08	1.00	0.17	0.89	0.37	0.73	0.21	0.67	0.17	0.70	0.22
TC-21-10-2-4-2	0.84	0.04	0.85	0.19	0.65	0.21	0.67	0.17	0.69	0.20	0.67	0.16
TC-21-10-3-4-2	0.63	0.10	0.72	0.11	0.85	0.29	0.68	0.18	0.71	0.16	0.67	0.17
TC-21-10-4-4-2	0.55	0.04	0.56	0.12	0.72	0.17	0.74	0.19	0.70	0.21	0.73	0.17
TC-21-10-5-4-2	0.79	0.05	0.85	0.16	0.89	0.20	0.73	0.22	0.64	0.14	0.70	0.14
TC-21-10-1-4-3	1.16	0.10	1.39	0.23	1.25	0.30	1.14	0.26	1.31	0.30	1.11	0.27
TC-21-10-2-4-3	0.91	0.08	1.22	0.25	1.06	0.24	1.08	0.30	1.40	0.49	1.56	0.47
TC-21-10-3-4-3	1.17	0.07	1.24	0.18	1.28	0.35	1.12	0.25	1.05	0.27	1.08	0.31
TC-21-10-4-4-3	0.91	0.05	1.02	0.18	1.13	0.26	1.23	0.27	1.19	0.27	1.13	0.25
TC-21-10-5-4-3	0.91	0.04	1.15	0.23	1.25	0.17	1.14	0.34	1.18	0.26	1.15	0.28
TC-21-10-1-5-1	0.17	0.00	0.17	0.00	0.16	0.01	0.16	0.01	0.16	0.00	0.16	0.01
TC-21-10-2-5-1	0.19	0.01	0.19	0.00	0.19	0.01	0.19	0.00	0.19	0.01	0.19	0.00
TC-21-10-3-5-1	0.15	0.00	0.15	0.00	0.15	0.00	0.15	0.00	0.15	0.00	0.15	0.01
TC-21-10-4-5-1	0.19	0.01	0.19	0.01	0.19	0.01	0.20	0.01	0.19	0.01	0.19	0.01
TC-21-10-5-5-1	0.21	0.01	0.21	0.00	0.21	0.00	0.21	0.00	0.21	0.01	0.21	0.01
TC-21-10-1-5-2	1.21	0.10	1.33	0.19	0.93	0.34	0.87	0.25	0.84	0.22	0.87	0.31
TC-21-10-2-5-2	1.21	0.07	1.00	0.20	0.81	0.20	0.80	0.23	0.73	0.18	0.90	0.21
TC-21-10-3-5-2	1.00	0.19	0.74	0.16	1.00	0.42	0.93	0.34	0.90	0.22	0.80	0.18
TC-21-10-4-5-2	0.92	0.06	0.75	0.14	0.85	0.20	0.88	0.22	0.83	0.26	0.89	0.27
TC-21-10-5-5-2	1.04	0.18	0.99	0.17	1.03	0.24	0.88	0.22	0.85	0.21	0.79	0.23
TC-21-10-1-5-3	1.75	0.07	2.01	0.52	1.67	0.68	1.47	0.37	1.35	0.32	1.43	0.35
TC-21-10-2-5-3	1.42	0.12	1.81	0.44	1.34	0.38	1.36	0.36	1.50	0.76	1.43	0.49
TC-21-10-3-5-3	1.80	0.10	1.71	0.41	1.91	0.97	1.38	0.50	1.32	0.42	1.29	0.26
TC-21-10-4-5-3	1.13	0.15	1.27	0.18	1.40	0.34	1.37	0.27	1.42	0.41	1.26	0.29
TC-21-10-5-5-3	1.54	0.07	1.98	0.88	1.71	0.60	1.41	0.60	1.56	0.50	1.92	0.67

Table A.16: Time consumation (s) for node-disjointness on TC-21-10 instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TE-21-5-1-3-1	374	374	374	374	238	238	238	238	238	238
TE-21-5-2-3-1	304	304	304	304	174	174	174	174	174	174
TE-21-5-3-3-1	328	328	328	328	224	224	224	224	224	224
TE-21-5-4-3-1	371	371	371	371	218	218	218	218	218	218
TE-21-5-5-3-1	381	381	381	381	268	268	268	268	268	268
TE-21-5-1-3-2	540	718	612	652	718	582	500	500	500	500
TE-21-5-2-3-2	346	600	428	503	600	406	374	374	374	374
TE-21-5-3-3-2	432	733	560	614	733	471	469	469	469	469
TE-21-5-4-3-2	376	665	523	681	665	479	434	434	434	434
TE-21-5-5-3-2	556	707	609	726	707	521	546	546	546	546
TE-21-5-1-3-3	736	1067	837	900	1067	777	728	728	728	728
TE-21-5-2-3-3	598	980	680	776	980	638	568	568	568	568
TE-21-5-3-3-3	630	1234	753	869	1234	713	699	699	699	699
TE-21-5-4-3-3	602	1011	741	960	1011	750	607	607	607	607
TE-21-5-5-3-3	799	1077	977	1098	1077	815	874	874	874	874
TE-21-5-1-4-1	374	374	374	374	238	238	238	238	238	238
TE-21-5-2-4-1	304	304	304	304	174	174	174	174	174	174
TE-21-5-3-4-1	328	328	328	328	224	224	224	224	224	224
TE-21-5-4-4-1	371	371	371	371	218	218	218	218	218	218
TE-21-5-5-4-1	381	381	381	381	268	268	268	268	268	268
TE-21-5-1-4-2	423	718	491	652	718	423	500	500	500	500
TE-21-5-2-4-2	379	600	421	503	600	421	362	362	362	362
TE-21-5-3-4-2	425	733	425	614	733	435	469	469	469	469
TE-21-5-4-4-2	370	665	404	681	665	376	434	434	434	434
TE-21-5-5-4-2	520	707	639	726	707	550	546	546	546	546
TE-21-5-1-4-3	663	1067	848	900	1067	729	728	728	728	728
TE-21-5-2-4-3	599	980	688	776	980	666	556	556	556	556
TE-21-5-3-4-3	616	1234	719	869	1234	665	699	699	699	699
TE-21-5-4-4-3	572	1011	682	960	1011	614	607	607	607	607
TE-21-5-5-4-3	815	1077	1003	1098	1077	813	874	874	874	874
TE-21-5-1-5-1	374	374	374	374	238	238	238	238	238	238
TE-21-5-2-5-1	304	304	304	304	174	174	174	174	174	174
TE-21-5-3-5-1	328	328	328	328	224	224	224	224	224	224
TE-21-5-4-5-1	371	371	371	371	218	218	218	218	218	218
TE-21-5-5-5-1	381	381	381	381	268	268	268	268	268	268
TE-21-5-1-5-2	440	718	508	652	718	498	500	500	500	500
TE-21-5-2-5-2	420	600	538	503	600	482	362	362	362	362
TE-21-5-3-5-2	395	733	409	614	733	395	469	469	469	469
TE-21-5-4-5-2	398	665	408	681	665	408	434	434	434	434
TE-21-5-5-5-2	524	707	643	726	707	538	546	546	546	546
TE-21-5-1-5-3	638	1067	747	900	1067	648	728	728	728	728
TE-21-5-2-5-3	534	980	672	776	980	548	556	556	556	556
TE-21-5-3-5-3	613	1234	756	869	1234	623	699	699	699	699
TE-21-5-4-5-3	584	1011	650	960	1011	626	607	607	607	607
TE-21-5-5-5-3	762	1077	876	1098	1077	770	874	874	874	874

Table A.17: Results for node-disjointness on TE-21-5 instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TE-21-5-1-3-1	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
TE-21-5-2-3-1	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TE-21-5-3-3-1	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
TE-21-5-4-3-1	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
TE-21-5-5-3-1	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00
TE-21-5-1-3-2	0.64	0.01	0.44	0.01	0.01	0.43	0.01	0.01	0.01	0.01
TE-21-5-2-3-2	0.43	0.00	0.28	0.00	0.01	0.23	0.01	0.00	0.00	0.00
TE-21-5-3-3-2	0.34	0.01	0.23	0.01	0.00	0.26	0.01	0.01	0.01	0.01
TE-21-5-4-3-2	0.55	0.01	0.41	0.01	0.01	0.37	0.01	0.01	0.01	0.01
TE-21-5-5-3-2	0.41	0.00	0.36	0.01	0.00	0.31	0.01	0.00	0.01	0.00
TE-21-5-1-3-3	0.77	0.00	0.63	0.00	0.01	0.55	0.01	0.01	0.01	0.00
TE-21-5-2-3-3	0.65	0.00	0.45	0.01	0.01	0.48	0.00	0.01	0.01	0.01
TE-21-5-3-3-3	0.49	0.01	0.35	0.01	0.00	0.39	0.01	0.00	0.01	0.00
TE-21-5-4-3-3	0.79	0.01	0.50	0.00	0.01	0.42	0.01	0.01	0.00	0.01
TE-21-5-5-3-3	0.52	0.00	0.47	0.01	0.01	0.44	0.00	0.00	0.01	0.00
TE-21-5-1-4-1	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TE-21-5-2-4-1	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
TE-21-5-3-4-1	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01
TE-21-5-4-4-1	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
TE-21-5-5-4-1	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00
TE-21-5-1-4-2	0.46	0.01	0.34	0.01	0.00	0.20	0.01	0.01	0.01	0.02
TE-21-5-2-4-2	0.28	0.00	0.23	0.00	0.01	0.20	0.01	0.01	0.00	0.01
TE-21-5-3-4-2	0.25	0.01	0.19	0.01	0.01	0.19	0.01	0.02	0.01	0.01
TE-21-5-4-4-2	0.60	0.01	0.37	0.00	0.01	0.15	0.01	0.01	0.01	0.00
TE-21-5-5-4-2	0.47	0.00	0.32	0.01	0.00	0.27	0.01	0.01	0.01	0.01
TE-21-5-1-4-3	0.96	0.01	0.80	0.02	0.01	0.66	0.00	0.00	0.01	0.02
TE-21-5-2-4-3	0.54	0.01	0.47	0.02	0.01	0.48	0.00	0.01	0.01	0.01
TE-21-5-3-4-3	0.57	0.01	0.37	0.01	0.01	0.46	0.01	0.01	0.01	0.01
TE-21-5-4-4-3	0.90	0.01	0.47	0.01	0.00	0.21	0.01	0.01	0.01	0.01
TE-21-5-5-4-3	0.63	0.01	0.50	0.01	0.01	0.41	0.01	0.01	0.00	0.01
TE-21-5-1-5-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
TE-21-5-2-5-1	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01
TE-21-5-3-5-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
TE-21-5-4-5-1	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
TE-21-5-5-5-1	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01
TE-21-5-1-5-2	0.58	0.02	0.36	0.01	0.00	0.23	0.01	0.01	0.01	0.02
TE-21-5-2-5-2	0.37	0.00	0.25	0.01	0.01	0.20	0.00	0.01	0.01	0.02
TE-21-5-3-5-2	0.32	0.00	0.21	0.01	0.01	0.18	0.01	0.01	0.01	0.02
TE-21-5-4-5-2	0.75	0.00	0.45	0.01	0.00	0.16	0.01	0.01	0.01	0.00
TE-21-5-5-5-2	0.36	0.01	0.24	0.01	0.01	0.25	0.01	0.01	0.01	0.01
TE-21-5-1-5-3	1.53	0.01	2.06	0.02	0.01	1.10	0.02	0.01	0.01	0.01
TE-21-5-2-5-3	0.42	0.01	0.38	0.02	0.00	0.30	0.01	0.01	0.01	0.02
TE-21-5-3-5-3	0.82	0.01	0.51	0.01	0.01	0.66	0.01	0.01	0.01	0.01
TE-21-5-4-5-3	1.21	0.01	0.58	0.02	0.00	0.26	0.02	0.02	0.02	0.01
TE-21-5-5-5-3	1.31	0.00	0.85	0.01	0.01	0.67	0.01	0.01	0.01	0.02

Table A.18: Time consumation (s) for node-disjointness on TE-21-5 instances.

	VND with									
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TE-21-5-1-3-1	200	200	200	200	208	208	208	208	208	208
TE-21-5-2-3-1	159	159	159	159	149	149	149	149	149	149
TE-21-5-3-3-1	191	191	191	191	191	191	191	191	191	191
TE-21-5-4-3-1	200	200	200	200	202	202	202	202	202	202
TE-21-5-5-3-1	219	219	219	219	244	244	244	244	244	244
TE-21-5-1-3-2	448	404	435	390	404	435	434	434	434	434
TE-21-5-2-3-2	319	301	387	303	301	387	288	288	288	288
TE-21-5-3-3-2	385	349	385	349	349	385	389	389	389	389
TE-21-5-4-3-2	368	413	429	368	413	421	368	368	368	368
TE-21-5-5-3-2	462	435	462	440	435	500	472	472	472	472
TE-21-5-1-3-3	679	622	670	532	622	670	614	614	614	614
TE-21-5-2-3-3	494	411	445	383	411	504	487	487	487	487
TE-21-5-3-3-3	577	604	577	519	604	577	575	575	575	575
TE-21-5-4-3-3	560	581	655	564	581	653	537	537	537	537
TE-21-5-5-3-3	771	650	741	634	650	769	634	634	634	634
TE-21-5-1-4-1	200	200	200	200	208	208	208	208	208	208
TE-21-5-2-4-1	159	159	159	159	149	149	149	149	149	149
TE-21-5-3-4-1	191	191	191	191	191	191	191	191	191	191
TE-21-5-4-4-1	200	200	200	200	202	202	202	202	202	202
TE-21-5-5-4-1	219	219	219	219	244	244	244	244	244	244
TE-21-5-1-4-2	406	374	452	389	374	406	434	434	434	434
TE-21-5-2-4-2	328	296	309	293	296	299	270	270	270	270
TE-21-5-3-4-2	390	313	390	311	313	390	319	319	319	319
TE-21-5-4-4-2	370	413	347	360	413	350	360	360	360	360
TE-21-5-5-4-2	476	405	466	374	405	476	414	414	414	414
TE-21-5-1-4-3	591	548	567	518	548	577	478	478	478	478
TE-21-5-2-4-3	433	411	404	383	411	404	411	411	411	411
TE-21-5-3-4-3	605	497	602	519	497	614	575	575	575	575
TE-21-5-4-4-3	546	581	587	537	581	463	537	537	537	537
TE-21-5-5-4-3	728	627	623	609	627	728	634	634	634	634
TE-21-5-1-5-1	200	200	200	200	208	208	208	208	208	208
TE-21-5-2-5-1	159	159	159	159	149	149	149	149	149	149
TE-21-5-3-5-1	191	191	191	191	191	191	191	191	191	191
TE-21-5-4-5-1	200	200	200	200	202	202	202	202	202	202
TE-21-5-5-5-1	219	219	219	219	244	244	244	244	244	244
TE-21-5-1-5-2	360	370	410	375	370	410	402	402	402	402
TE-21-5-2-5-2	287	262	278	293	262	267	226	226	226	226
TE-21-5-3-5-2	375	313	375	311	313	375	319	319	319	319
TE-21-5-4-5-2	330	413	338	340	413	338	340	340	340	340
TE-21-5-5-5-2	437	400	424	344	400	449	414	414	414	414
TE-21-5-1-5-3	504	548	550	518	548	519	478	478	478	478
TE-21-5-2-5-3	502	411	413	383	411	485	411	411	411	411
TE-21-5-3-5-3	523	496	549	519	496	544	575	575	575	575
TE-21-5-4-5-3	497	581	490	535	581	463	537	537	537	537
TE-21-5-5-5-3	658	627	663	609	627	656	634	634	634	634

Table A.19: Results for node-disjointness on TE-21-5 instances.

	VND with									
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TE-21-5-1-3-1	0.04	0.05	0.04	0.04	0.02	0.02	0.03	0.03	0.03	0.03
TE-21-5-2-3-1	0.04	0.03	0.04	0.04	0.03	0.03	0.04	0.03	0.02	0.03
TE-21-5-3-3-1	0.04	0.04	0.05	0.04	0.04	0.02	0.03	0.03	0.03	0.03
TE-21-5-4-3-1	0.05	0.06	0.04	0.04	0.02	0.02	0.02	0.02	0.02	0.02
TE-21-5-5-3-1	0.04	0.05	0.03	0.04	0.02	0.02	0.02	0.02	0.03	0.02
TE-21-5-1-3-2	0.76	0.09	0.54	0.14	0.09	0.52	0.06	0.06	0.06	0.05
TE-21-5-2-3-2	0.47	0.12	0.35	0.10	0.13	0.27	0.07	0.07	0.08	0.08
TE-21-5-3-3-2	0.40	0.09	0.33	0.11	0.09	0.36	0.06	0.06	0.06	0.07
TE-21-5-4-3-2	0.60	0.10	0.49	0.12	0.09	0.40	0.05	0.05	0.05	0.06
TE-21-5-5-3-2	0.54	0.11	0.48	0.08	0.11	0.34	0.07	0.06	0.06	0.06
TE-21-5-1-3-3	0.86	0.18	0.76	0.17	0.19	0.64	0.08	0.08	0.08	0.08
TE-21-5-2-3-3	0.76	0.15	0.65	0.20	0.15	0.64	0.10	0.10	0.10	0.10
TE-21-5-3-3-3	0.63	0.17	0.48	0.22	0.17	0.51	0.11	0.11	0.11	0.11
TE-21-5-4-3-3	0.83	0.16	0.56	0.15	0.17	0.47	0.09	0.09	0.09	0.10
TE-21-5-5-3-3	0.61	0.20	0.66	0.19	0.20	0.53	0.10	0.10	0.10	0.10
TE-21-5-1-4-1	0.05	0.04	0.05	0.05	0.02	0.03	0.02	0.03	0.03	0.03
TE-21-5-2-4-1	0.05	0.04	0.05	0.05	0.03	0.04	0.04	0.04	0.03	0.03
TE-21-5-3-4-1	0.05	0.04	0.05	0.05	0.03	0.04	0.04	0.03	0.03	0.03
TE-21-5-4-4-1	0.05	0.04	0.04	0.04	0.02	0.02	0.02	0.02	0.02	0.02
TE-21-5-5-4-1	0.04	0.05	0.05	0.05	0.03	0.02	0.03	0.04	0.03	0.04
TE-21-5-1-4-2	0.55	0.12	0.40	0.16	0.13	0.30	0.06	0.06	0.06	0.06
TE-21-5-2-4-2	0.33	0.15	0.36	0.14	0.17	0.33	0.10	0.10	0.11	0.11
TE-21-5-3-4-2	0.35	0.13	0.30	0.16	0.13	0.26	0.11	0.10	0.10	0.10
TE-21-5-4-4-2	0.63	0.10	0.47	0.13	0.11	0.21	0.08	0.08	0.09	0.08
TE-21-5-5-4-2	0.58	0.15	0.41	0.14	0.15	0.36	0.11	0.11	0.11	0.10
TE-21-5-1-4-3	1.27	0.23	1.09	0.32	0.26	0.86	0.12	0.14	0.14	0.13
TE-21-5-2-4-3	0.85	0.18	0.81	0.23	0.16	0.84	0.17	0.17	0.17	0.16
TE-21-5-3-4-3	0.63	0.26	0.51	0.26	0.27	0.60	0.13	0.13	0.12	0.13
TE-21-5-4-4-3	0.98	0.18	0.58	0.19	0.19	0.44	0.11	0.11	0.11	0.11
TE-21-5-5-4-3	0.70	0.27	0.74	0.19	0.27	0.48	0.12	0.12	0.11	0.12
TE-21-5-1-5-1	0.05	0.05	0.05	0.05	0.03	0.04	0.04	0.04	0.02	0.03
TE-21-5-2-5-1	0.06	0.06	0.05	0.05	0.04	0.03	0.04	0.04	0.04	0.04
TE-21-5-3-5-1	0.05	0.05	0.05	0.06	0.04	0.04	0.05	0.03	0.04	0.04
TE-21-5-4-5-1	0.05	0.05	0.06	0.06	0.03	0.03	0.03	0.03	0.03	0.03
TE-21-5-5-5-1	0.06	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.04	0.04
TE-21-5-1-5-2	0.78	0.14	0.42	0.20	0.15	0.30	0.09	0.10	0.09	0.09
TE-21-5-2-5-2	0.54	0.21	0.41	0.15	0.20	0.46	0.14	0.14	0.15	0.15
TE-21-5-3-5-2	0.41	0.14	0.35	0.17	0.14	0.27	0.11	0.11	0.11	0.11
TE-21-5-4-5-2	0.83	0.12	0.51	0.18	0.12	0.22	0.12	0.12	0.12	0.12
TE-21-5-5-5-2	0.48	0.16	0.41	0.18	0.16	0.39	0.13	0.12	0.12	0.12
TE-21-5-1-5-3	1.81	0.22	2.31	0.23	0.22	1.34	0.12	0.13	0.13	0.13
TE-21-5-2-5-3	0.52	0.19	0.61	0.26	0.19	0.41	0.19	0.20	0.19	0.19
TE-21-5-3-5-3	1.08	0.30	0.79	0.29	0.30	0.86	0.14	0.15	0.15	0.14
TE-21-5-4-5-3	1.43	0.21	0.84	0.22	0.21	0.57	0.13	0.13	0.12	0.12
TE-21-5-5-5-3	1.48	0.30	1.05	0.23	0.30	0.89	0.13	0.14	0.14	0.13

Table A.20: Time consumation (s) for node-disjointness on TE-21-5 instances.

	MSVND with											
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TE-21-5-1-3-1	200.47	0.86	200.67	0.96	200.67	0.96	200.53	0.90	200.67	0.96	200.47	0.86
TE-21-5-2-3-1	149.00	0.00	149.00	0.00	149.00	0.00	149.00	0.00	149.00	0.00	149.67	2.54
TE-21-5-3-3-1	191.40	2.19	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00
TE-21-5-4-3-1	184.10	4.99	181.83	2.88	182.93	5.02	183.77	5.30	183.00	5.29	183.73	5.78
TE-21-5-5-3-1	216.00	0.00	216.10	0.55	216.00	0.00	216.00	0.00	216.00	0.00	216.00	0.00
TE-21-5-1-3-2	404.00	0.00	404.00	0.00	404.00	0.00	380.03	6.75	380.80	8.39	381.60	7.21
TE-21-5-2-3-2	301.00	0.00	301.00	0.00	301.00	0.00	290.90	6.74	291.13	6.93	292.30	8.59
TE-21-5-3-3-2	349.00	0.00	349.00	0.00	349.00	0.00	361.33	7.41	361.80	6.94	361.47	7.00
TE-21-5-4-3-2	413.00	0.00	413.00	0.00	413.00	0.00	358.87	16.62	356.10	15.46	364.23	13.18
TE-21-5-5-3-2	435.00	0.00	435.00	0.00	435.00	0.00	423.67	13.76	420.57	13.29	419.37	13.72
TE-21-5-1-3-3	622.00	0.00	622.00	0.00	622.00	0.00	579.97	12.66	582.93	18.15	577.03	12.34
TE-21-5-2-3-3	411.00	0.00	411.00	0.00	411.00	0.00	411.00	21.43	409.33	17.05	403.43	18.08
TE-21-5-3-3-3	604.00	0.00	604.00	0.00	604.00	0.00	506.07	8.71	507.20	10.77	507.93	14.65
TE-21-5-4-3-3	581.00	0.00	581.00	0.00	581.00	0.00	520.33	17.59	527.43	15.38	529.70	19.19
TE-21-5-5-3-3	650.00	0.00	650.00	0.00	650.00	0.00	630.20	7.39	629.97	7.95	627.57	5.96
TE-21-5-1-4-1	200.27	0.69	200.40	0.81	200.60	0.93	200.80	1.00	200.60	1.07	200.47	0.86
TE-21-5-2-4-1	149.00	0.00	149.00	0.00	149.00	0.00	149.00	0.00	149.00	0.00	149.00	0.00
TE-21-5-3-4-1	191.40	2.19	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00
TE-21-5-4-4-1	183.10	4.43	182.57	1.72	182.43	3.04	183.27	3.91	182.73	3.13	182.00	1.58
TE-21-5-5-4-1	216.00	0.00	216.10	0.55	216.00	0.00	216.10	0.55	216.10	0.55	216.00	0.00
TE-21-5-1-4-2	374.00	0.00	374.00	0.00	374.00	0.00	372.10	11.66	369.67	13.16	369.00	14.22
TE-21-5-2-4-2	296.00	0.00	296.00	0.00	296.00	0.00	270.57	8.58	273.60	9.29	272.37	8.88
TE-21-5-3-4-2	313.00	0.00	313.00	0.00	313.00	0.00	311.33	1.49	313.40	11.73	311.13	0.51
TE-21-5-4-4-2	413.00	0.00	413.00	0.00	413.00	0.00	326.67	12.44	326.53	11.46	327.70	13.55
TE-21-5-5-4-2	405.00	0.00	405.00	0.00	405.00	0.00	382.43	6.43	381.43	2.34	381.53	2.26
TE-21-5-1-4-3	548.00	0.00	548.00	0.00	548.00	0.00	512.20	19.85	508.87	19.56	512.63	23.39
TE-21-5-2-4-3	411.00	0.00	411.00	0.00	411.00	0.00	385.90	7.54	388.63	9.52	390.40	10.79
TE-21-5-3-4-3	497.00	0.00	497.00	0.00	497.00	0.00	498.67	6.60	499.47	6.82	500.80	4.53
TE-21-5-4-4-3	581.00	0.00	581.00	0.00	581.00	0.00	505.53	17.42	502.23	17.81	502.03	19.41
TE-21-5-5-4-3	627.00	0.00	627.00	0.00	627.00	0.00	577.43	28.27	571.63	23.51	582.70	22.55
TE-21-5-1-5-1	200.73	1.11	200.80	1.13	200.60	0.93	200.47	0.86	200.40	0.81	201.00	1.64
TE-21-5-2-5-1	149.00	0.00	149.00	0.00	149.00	0.00	149.00	0.00	149.00	0.00	149.00	0.00
TE-21-5-3-5-1	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00
TE-21-5-4-5-1	183.87	4.55	183.13	2.97	183.60	4.16	181.63	1.85	182.90	4.45	181.77	1.55
TE-21-5-5-5-1	216.00	0.00	216.20	0.76	216.00	0.00	216.10	0.55	216.00	0.00	216.30	0.92
TE-21-5-1-5-2	370.00	0.00	370.00	0.00	370.00	0.00	341.00	26.49	340.97	26.16	340.23	24.85
TE-21-5-2-5-2	262.00	0.00	262.00	0.00	262.00	0.00	226.00	0.00	226.00	0.00	226.30	1.64
TE-21-5-3-5-2	313.00	0.00	313.00	0.00	313.00	0.00	293.83	20.24	293.67	22.19	292.47	21.56
TE-21-5-4-5-2	413.00	0.00	413.00	0.00	413.00	0.00	312.63	7.04	312.17	8.62	313.27	9.55
TE-21-5-5-5-2	400.00	0.00	400.00	0.00	400.00	0.00	337.37	5.66	338.03	5.50	338.50	7.41
TE-21-5-1-5-3	548.00	0.00	548.00	0.00	548.00	0.00	503.57	21.38	504.70	23.70	495.87	19.80
TE-21-5-2-5-3	411.00	0.00	411.00	0.00	411.00	0.00	389.57	10.37	389.60	10.28	388.10	9.51
TE-21-5-3-5-3	496.00	0.00	496.00	0.00	496.00	0.00	500.00	4.95	499.30	5.21	498.07	7.86
TE-21-5-4-5-3	581.00	0.00	581.00	0.00	581.00	0.00	502.90	15.94	500.13	14.54	501.40	15.04
TE-21-5-5-5-3	627.00	0.00	627.00	0.00	627.00	0.00	548.70	18.11	556.33	26.30	544.27	22.22

Table A.21: Results for node-disjointness on TE-21-5 instances.

	MSVND with											
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TE-21-5-1-3-1	0.24	0.02	0.24	0.02	0.23	0.03	0.24	0.02	0.23	0.03	0.24	0.02
TE-21-5-2-3-1	0.27	0.02	0.28	0.02	0.27	0.02	0.28	0.02	0.28	0.02	0.28	0.02
TE-21-5-3-3-1	0.28	0.02	0.28	0.02	0.28	0.02	0.29	0.02	0.28	0.02	0.28	0.02
TE-21-5-4-3-1	0.24	0.03	0.25	0.03	0.23	0.03	0.24	0.03	0.24	0.03	0.25	0.03
TE-21-5-5-3-1	0.28	0.02	0.28	0.03	0.28	0.02	0.28	0.02	0.27	0.03	0.29	0.02
TE-21-5-1-3-2	0.78	0.00	0.78	0.01	0.81	0.11	0.58	0.02	0.57	0.03	0.58	0.04
TE-21-5-2-3-2	1.16	0.02	1.17	0.02	1.16	0.01	0.61	0.04	0.65	0.12	0.62	0.03
TE-21-5-3-3-2	0.81	0.01	0.81	0.00	0.81	0.01	0.70	0.04	0.71	0.05	0.70	0.05
TE-21-5-4-3-2	0.85	0.03	0.90	0.14	0.84	0.01	0.57	0.05	0.60	0.09	0.65	0.13
TE-21-5-5-3-2	1.04	0.01	1.04	0.01	1.04	0.01	0.54	0.05	0.53	0.04	0.54	0.04
TE-21-5-1-3-3	1.71	0.01	1.70	0.01	1.69	0.01	0.89	0.08	0.87	0.07	0.89	0.08
TE-21-5-2-3-3	1.35	0.01	1.35	0.01	1.35	0.01	0.93	0.07	0.90	0.07	0.91	0.07
TE-21-5-3-3-3	1.60	0.07	1.59	0.06	1.58	0.00	1.02	0.08	1.03	0.07	1.03	0.07
TE-21-5-4-3-3	1.53	0.04	1.50	0.02	1.50	0.01	0.96	0.09	0.98	0.09	0.96	0.10
TE-21-5-5-3-3	1.80	0.01	1.80	0.00	1.81	0.02	0.96	0.07	0.93	0.07	0.93	0.07
TE-21-5-1-4-1	0.25	0.02	0.24	0.02	0.24	0.02	0.26	0.02	0.25	0.03	0.25	0.03
TE-21-5-2-4-1	0.30	0.02	0.29	0.02	0.29	0.02	0.28	0.02	0.29	0.02	0.29	0.02
TE-21-5-3-4-1	0.30	0.03	0.37	0.09	0.29	0.02	0.29	0.02	0.29	0.02	0.30	0.02
TE-21-5-4-4-1	0.22	0.02	0.22	0.02	0.22	0.02	0.23	0.02	0.24	0.03	0.24	0.02
TE-21-5-5-4-1	0.28	0.02	0.29	0.02	0.29	0.02	0.28	0.02	0.29	0.02	0.29	0.02
TE-21-5-1-4-2	1.19	0.01	1.19	0.01	1.19	0.01	0.78	0.07	0.78	0.06	0.78	0.06
TE-21-5-2-4-2	1.51	0.01	1.51	0.01	1.51	0.01	0.89	0.06	0.89	0.07	0.90	0.05
TE-21-5-3-4-2	1.12	0.01	1.13	0.05	1.12	0.01	0.89	0.06	0.90	0.05	0.89	0.06
TE-21-5-4-4-2	0.95	0.00	0.95	0.01	0.95	0.01	0.95	0.12	0.92	0.10	0.93	0.09
TE-21-5-5-4-2	1.37	0.01	1.37	0.00	1.37	0.01	0.87	0.05	0.86	0.04	0.89	0.05
TE-21-5-1-4-3	2.18	0.31	2.55	0.36	1.88	0.15	1.35	0.25	1.26	0.11	1.30	0.09
TE-21-5-2-4-3	1.54	0.01	1.54	0.01	1.54	0.01	1.30	0.08	1.26	0.11	1.29	0.11
TE-21-5-3-4-3	2.42	0.01	2.48	0.26	2.46	0.17	1.42	0.07	1.51	0.27	1.40	0.10
TE-21-5-4-4-3	1.69	0.01	1.69	0.01	1.69	0.01	1.26	0.11	1.28	0.10	1.30	0.12
TE-21-5-5-4-3	2.43	0.01	2.43	0.01	2.43	0.01	1.27	0.13	1.29	0.13	1.26	0.09
TE-21-5-1-5-1	0.28	0.02	0.27	0.02	0.28	0.03	0.29	0.03	0.27	0.03	0.27	0.03
TE-21-5-2-5-1	0.33	0.02	0.33	0.03	0.33	0.03	0.34	0.02	0.34	0.02	0.34	0.02
TE-21-5-3-5-1	0.33	0.03	0.34	0.03	0.34	0.03	0.34	0.02	0.33	0.03	0.34	0.03
TE-21-5-4-5-1	0.25	0.02	0.25	0.02	0.25	0.02	0.25	0.02	0.26	0.03	0.25	0.02
TE-21-5-5-5-1	0.32	0.02	0.32	0.02	0.32	0.02	0.33	0.02	0.33	0.02	0.32	0.02
TE-21-5-1-5-2	1.43	0.24	1.44	0.23	1.42	0.21	1.06	0.07	1.09	0.09	1.07	0.07
TE-21-5-2-5-2	1.91	0.01	1.91	0.01	1.90	0.00	1.17	0.06	1.15	0.05	1.16	0.07
TE-21-5-3-5-2	1.26	0.01	1.26	0.00	1.26	0.01	1.04	0.06	1.04	0.07	1.04	0.07
TE-21-5-4-5-2	1.06	0.01	1.06	0.01	1.06	0.01	1.20	0.12	1.16	0.08	1.18	0.11
TE-21-5-5-5-2	1.52	0.01	1.52	0.01	1.64	0.27	1.24	0.10	1.24	0.09	1.26	0.22
TE-21-5-1-5-3	2.04	0.01	2.04	0.01	2.04	0.01	1.58	0.14	1.59	0.15	1.57	0.10
TE-21-5-2-5-3	1.75	0.01	1.75	0.01	1.74	0.01	1.42	0.09	1.41	0.10	1.44	0.09
TE-21-5-3-5-3	2.73	0.01	2.72	0.01	2.73	0.01	1.62	0.11	1.88	0.45	1.62	0.14
TE-21-5-4-5-3	1.90	0.01	1.90	0.01	1.90	0.01	1.56	0.12	1.63	0.15	1.59	0.10
TE-21-5-5-5-3	2.73	0.01	2.75	0.03	2.73	0.01	1.47	0.11	1.49	0.17	1.47	0.14

Table A.22: Time consumation (s) for node-disjointness on TE-21-5 instances.

	GRASP											
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TE-21-5-1-3-1	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00
TE-21-5-2-3-1	159.00	0.00	159.00	0.00	159.00	0.00	159.00	0.00	159.00	0.00	159.00	0.00
TE-21-5-3-3-1	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00
TE-21-5-4-3-1	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00
TE-21-5-5-3-1	219.00	0.00	219.00	0.00	219.00	0.00	219.00	0.00	219.00	0.00	219.00	0.00
TE-21-5-1-3-2	449.23	27.99	443.97	25.95	436.83	20.59	436.73	40.91	477.43	53.36	477.57	69.20
TE-21-5-2-3-2	319.00	0.00	333.37	21.08	337.77	21.47	353.87	38.66	417.83	72.80	376.83	62.17
TE-21-5-3-3-2	385.00	0.00	392.60	12.36	407.13	21.64	408.17	36.25	448.87	60.34	446.40	73.86
TE-21-5-4-3-2	386.90	14.68	387.53	23.81	394.20	25.16	420.00	42.47	442.47	58.54	445.83	64.60
TE-21-5-5-3-2	489.20	24.19	495.03	21.44	501.37	29.16	512.23	39.60	492.23	48.48	513.73	58.52
TE-21-5-1-3-3	679.00	0.00	668.83	33.52	665.93	19.66	638.67	47.30	675.67	60.67	693.37	75.45
TE-21-5-2-3-3	504.37	15.09	508.70	28.40	522.00	31.03	504.60	61.88	507.33	72.59	554.90	74.32
TE-21-5-3-3-3	580.73	3.55	597.47	23.18	613.63	30.57	614.40	46.42	645.13	76.04	612.70	54.43
TE-21-5-4-3-3	586.90	23.49	589.40	35.31	588.93	32.12	606.40	50.88	631.00	68.75	638.87	80.95
TE-21-5-5-3-3	773.20	6.75	769.47	19.27	767.33	30.49	722.90	43.89	730.17	63.40	723.10	71.73
TE-21-5-1-4-1	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00
TE-21-5-2-4-1	159.00	0.00	159.00	0.00	159.00	0.00	159.00	0.00	159.00	0.00	159.00	0.00
TE-21-5-3-4-1	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00
TE-21-5-4-4-1	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00
TE-21-5-5-4-1	219.00	0.00	219.00	0.00	219.00	0.00	219.00	0.00	219.00	0.00	219.00	0.00
TE-21-5-1-4-2	394.80	10.66	400.87	22.69	398.93	35.10	434.87	59.09	420.43	48.54	448.23	62.26
TE-21-5-2-4-2	328.00	0.00	321.87	20.62	331.10	41.21	335.33	43.07	375.90	64.69	369.07	69.14
TE-21-5-3-4-2	390.00	0.00	392.37	9.50	380.50	33.50	396.30	55.58	442.50	78.53	416.60	68.37
TE-21-5-4-4-2	373.13	18.57	372.07	23.67	384.97	27.13	402.03	50.37	415.77	55.17	404.17	50.45
TE-21-5-5-4-2	447.37	21.08	456.17	21.79	463.37	39.00	457.27	43.85	462.97	54.29	492.13	54.95
TE-21-5-1-4-3	592.33	13.96	601.50	38.48	610.77	57.30	651.83	70.11	645.33	95.39	667.80	88.15
TE-21-5-2-4-3	451.67	13.42	453.10	40.42	496.87	60.53	491.13	55.82	523.93	72.61	511.43	70.51
TE-21-5-3-4-3	597.53	8.12	591.23	21.61	564.80	50.07	574.67	73.39	618.90	89.30	582.63	87.08
TE-21-5-4-4-3	529.67	22.55	537.90	30.92	565.40	38.34	613.47	66.82	592.40	68.98	602.07	52.95
TE-21-5-5-4-3	733.43	9.75	697.37	45.09	694.70	49.86	686.73	35.06	687.73	77.92	705.90	70.68
TE-21-5-1-5-1	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00
TE-21-5-2-5-1	159.00	0.00	159.00	0.00	159.00	0.00	159.00	0.00	159.00	0.00	159.00	0.00
TE-21-5-3-5-1	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00
TE-21-5-4-5-1	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00
TE-21-5-5-5-1	219.00	0.00	219.00	0.00	219.00	0.00	219.00	0.00	219.00	0.00	219.00	0.00
TE-21-5-1-5-2	360.00	0.00	377.47	29.52	401.97	44.40	419.97	67.52	416.87	67.03	434.70	71.10
TE-21-5-2-5-2	277.00	10.17	293.03	26.08	303.83	49.16	316.97	68.82	339.97	70.77	354.50	91.22
TE-21-5-3-5-2	373.50	2.33	372.70	22.14	364.23	43.16	364.47	51.15	393.07	79.58	403.80	77.31
TE-21-5-4-5-2	355.27	14.15	356.77	27.83	373.90	43.30	362.83	37.26	392.60	69.95	376.27	66.00
TE-21-5-5-5-2	437.00	0.00	428.03	29.81	429.37	38.74	441.87	50.29	453.17	76.63	472.03	76.34
TE-21-5-1-5-3	577.80	49.72	574.53	47.66	586.73	40.99	603.10	50.62	660.77	84.85	630.87	67.85
TE-21-5-2-5-3	502.00	0.00	451.03	46.51	468.90	57.75	468.30	65.09	504.23	67.76	506.43	76.52
TE-21-5-3-5-3	550.27	21.14	551.73	42.38	527.40	39.35	583.40	75.42	607.73	88.66	597.97	76.42
TE-21-5-4-5-3	539.13	27.39	533.93	34.94	542.93	30.48	582.67	53.53	560.17	53.71	599.70	75.03
TE-21-5-5-5-3	658.00	0.00	661.17	35.96	636.73	53.22	674.30	57.56	671.33	68.16	695.30	83.29

Table A.23: Results for node-disjointness on TE-21-5 instances.

	GRASP											
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TE-21-5-1-3-1	0.04	0.01	0.04	0.01	0.04	0.00	0.04	0.00	0.04	0.00	0.04	0.00
TE-21-5-2-3-1	0.04	0.00	0.04	0.00	0.04	0.00	0.04	0.00	0.04	0.00	0.04	0.00
TE-21-5-3-3-1	0.04	0.01	0.04	0.01	0.04	0.00	0.04	0.01	0.04	0.00	0.04	0.01
TE-21-5-4-3-1	0.05	0.01	0.05	0.00	0.05	0.00	0.05	0.01	0.05	0.01	0.05	0.01
TE-21-5-5-3-1	0.04	0.01	0.04	0.00	0.04	0.00	0.04	0.01	0.04	0.00	0.04	0.01
TE-21-5-1-3-2	0.71	0.03	0.64	0.08	0.47	0.12	0.31	0.10	0.32	0.10	0.28	0.09
TE-21-5-2-3-2	0.51	0.03	0.51	0.09	0.41	0.11	0.31	0.08	0.29	0.10	0.29	0.08
TE-21-5-3-3-2	0.43	0.03	0.41	0.07	0.33	0.08	0.30	0.07	0.30	0.09	0.28	0.07
TE-21-5-4-3-2	0.62	0.03	0.64	0.08	0.47	0.16	0.30	0.11	0.30	0.09	0.27	0.07
TE-21-5-5-3-2	0.50	0.03	0.48	0.05	0.40	0.10	0.38	0.13	0.31	0.08	0.27	0.09
TE-21-5-1-3-3	0.86	0.02	0.83	0.09	0.73	0.13	0.48	0.11	0.46	0.10	0.45	0.12
TE-21-5-2-3-3	0.74	0.06	0.74	0.09	0.66	0.14	0.49	0.16	0.43	0.09	0.44	0.09
TE-21-5-3-3-3	0.61	0.03	0.66	0.14	0.66	0.17	0.45	0.10	0.45	0.11	0.43	0.13
TE-21-5-4-3-3	0.82	0.02	0.90	0.06	0.80	0.23	0.42	0.09	0.51	0.21	0.45	0.09
TE-21-5-5-3-3	0.63	0.04	0.63	0.05	0.59	0.11	0.52	0.11	0.43	0.10	0.47	0.10
TE-21-5-1-4-1	0.05	0.01	0.05	0.00	0.05	0.00	0.05	0.01	0.05	0.00	0.05	0.00
TE-21-5-2-4-1	0.05	0.00	0.05	0.01	0.05	0.00	0.05	0.00	0.05	0.00	0.05	0.01
TE-21-5-3-4-1	0.05	0.00	0.05	0.01	0.05	0.00	0.05	0.01	0.05	0.00	0.05	0.01
TE-21-5-4-4-1	0.04	0.01	0.04	0.01	0.04	0.00	0.04	0.00	0.04	0.01	0.04	0.00
TE-21-5-5-4-1	0.05	0.00	0.05	0.00	0.05	0.00	0.05	0.01	0.05	0.00	0.05	0.01
TE-21-5-1-4-2	0.61	0.03	0.65	0.10	0.40	0.15	0.33	0.10	0.32	0.10	0.29	0.10
TE-21-5-2-4-2	0.34	0.02	0.44	0.08	0.34	0.13	0.29	0.08	0.30	0.07	0.31	0.09
TE-21-5-3-4-2	0.36	0.03	0.36	0.06	0.33	0.11	0.30	0.07	0.29	0.11	0.28	0.08
TE-21-5-4-4-2	0.74	0.04	0.77	0.11	0.47	0.21	0.33	0.12	0.30	0.08	0.33	0.08
TE-21-5-5-4-2	0.57	0.04	0.43	0.07	0.32	0.08	0.36	0.10	0.33	0.08	0.32	0.09
TE-21-5-1-4-3	1.07	0.04	0.95	0.11	0.82	0.19	0.54	0.17	0.55	0.11	0.51	0.17
TE-21-5-2-4-3	0.80	0.03	0.80	0.14	0.68	0.20	0.55	0.14	0.51	0.15	0.56	0.16
TE-21-5-3-4-3	0.60	0.03	0.62	0.10	0.57	0.15	0.56	0.14	0.57	0.16	0.52	0.15
TE-21-5-4-4-3	1.04	0.07	1.09	0.15	0.98	0.27	0.49	0.13	0.50	0.15	0.44	0.09
TE-21-5-5-4-3	0.70	0.04	0.70	0.12	0.56	0.11	0.59	0.17	0.51	0.15	0.55	0.15
TE-21-5-1-5-1	0.05	0.01	0.06	0.00	0.05	0.00	0.05	0.01	0.05	0.00	0.05	0.00
TE-21-5-2-5-1	0.05	0.00	0.06	0.00	0.06	0.00	0.05	0.00	0.05	0.00	0.06	0.00
TE-21-5-3-5-1	0.06	0.00	0.05	0.01	0.06	0.00	0.05	0.01	0.05	0.01	0.06	0.00
TE-21-5-4-5-1	0.05	0.01	0.05	0.01	0.05	0.01	0.05	0.01	0.05	0.01	0.05	0.01
TE-21-5-5-5-1	0.05	0.01	0.06	0.01	0.06	0.01	0.05	0.01	0.05	0.01	0.05	0.00
TE-21-5-1-5-2	0.85	0.16	0.79	0.14	0.66	0.18	0.34	0.09	0.40	0.15	0.32	0.10
TE-21-5-2-5-2	0.49	0.03	0.53	0.15	0.54	0.23	0.37	0.16	0.39	0.16	0.34	0.11
TE-21-5-3-5-2	0.46	0.04	0.41	0.07	0.37	0.15	0.38	0.14	0.37	0.11	0.37	0.10
TE-21-5-4-5-2	0.92	0.07	0.98	0.20	0.59	0.31	0.34	0.10	0.36	0.09	0.35	0.11
TE-21-5-5-5-2	0.42	0.03	0.47	0.10	0.34	0.08	0.38	0.12	0.35	0.15	0.34	0.12
TE-21-5-1-5-3	2.06	0.22	1.69	0.63	1.18	0.37	0.68	0.19	0.57	0.13	0.58	0.17
TE-21-5-2-5-3	0.56	0.02	0.88	0.24	0.80	0.33	0.61	0.15	0.53	0.14	0.59	0.17
TE-21-5-3-5-3	0.94	0.10	0.80	0.22	0.69	0.17	0.64	0.21	0.60	0.19	0.97	0.20
TE-21-5-4-5-3	1.32	0.07	1.43	0.20	1.13	0.36	0.54	0.16	0.59	0.20	0.60	0.14
TE-21-5-5-5-3	1.36	0.17	1.12	0.36	0.72	0.14	0.70	0.24	0.65	0.22	0.63	0.14

Table A.24: Time consumation (s) for node-disjointness on TE-21-5 instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TE-21-10-1-3-1	787	787	787	787	359	359	359	359	359	359
TE-21-10-2-3-1	634	634	634	634	339	339	339	339	339	339
TE-21-10-3-3-1	662	662	662	662	424	424	424	424	424	424
TE-21-10-4-3-1	683	683	683	683	327	327	327	327	327	327
TE-21-10-5-3-1	606	606	606	606	292	292	292	292	292	292
TE-21-10-1-3-2	786	1335	954	1294	1335	958	726	726	726	726
TE-21-10-2-3-2	725	1132	1030	1202	1132	842	767	767	767	767
TE-21-10-3-3-2	637	1365	837	1143	1365	747	775	775	775	775
TE-21-10-4-3-2	676	1183	939	1119	1183	841	749	749	749	749
TE-21-10-5-3-2	588	1180	802	1065	1180	620	624	624	624	624
TE-21-10-1-3-3	1113	1805	1403	1785	1805	1398	1212	1212	1212	1212
TE-21-10-2-3-3	999	1635	1367	1701	1635	1180	1113	1113	1113	1113
TE-21-10-3-3-3	891	2051	1321	1579	2051	1103	1133	1133	1133	1133
TE-21-10-4-3-3	925	1859	1295	1511	1859	1140	1142	1142	1142	1142
TE-21-10-5-3-3	826	1677	1161	1500	1677	932	1029	1029	1029	1029
TE-21-10-1-4-1	787	787	787	787	298	298	298	298	298	298
TE-21-10-2-4-1	634	634	634	634	309	309	309	309	309	309
TE-21-10-3-4-1	662	662	662	662	372	372	372	372	372	372
TE-21-10-4-4-1	683	683	683	683	315	315	315	315	315	315
TE-21-10-5-4-1	606	606	606	606	292	292	292	292	292	292
TE-21-10-1-4-2	632	1335	866	1294	1335	746	694	694	694	694
TE-21-10-2-4-2	604	1132	847	1202	1132	743	771	771	771	771
TE-21-10-3-4-2	600	1365	880	1143	1365	612	760	760	760	760
TE-21-10-4-4-2	594	1183	659	1119	1183	660	733	733	733	733
TE-21-10-5-4-2	460	1180	690	1065	1180	516	624	624	624	624
TE-21-10-1-4-3	945	1805	1154	1785	1805	1129	1199	1199	1199	1199
TE-21-10-2-4-3	852	1635	1205	1701	1635	988	1117	1117	1117	1117
TE-21-10-3-4-3	870	2051	1241	1579	2051	903	1128	1128	1128	1128
TE-21-10-4-4-3	814	1859	1053	1511	1859	999	1138	1138	1138	1138
TE-21-10-5-4-3	669	1677	1133	1500	1677	857	1029	1029	1029	1029
TE-21-10-1-5-1	787	787	787	787	287	287	287	287	287	287
TE-21-10-2-5-1	634	634	634	634	303	303	303	303	303	303
TE-21-10-3-5-1	662	662	662	662	372	372	372	372	372	372
TE-21-10-4-5-1	683	683	683	683	309	309	309	309	309	309
TE-21-10-5-5-1	606	606	606	606	292	292	292	292	292	292
TE-21-10-1-5-2	547	1335	783	1294	1335	721	694	694	694	694
TE-21-10-2-5-2	557	1132	693	1202	1132	645	771	771	771	771
TE-21-10-3-5-2	593	1365	727	1143	1365	601	760	760	760	760
TE-21-10-4-5-2	517	1183	613	1119	1183	601	752	752	752	752
TE-21-10-5-5-2	416	1180	579	1065	1180	452	624	624	624	624
TE-21-10-1-5-3	799	1805	1131	1785	1805	1052	1199	1199	1199	1199
TE-21-10-2-5-3	862	1635	1048	1701	1635	910	1117	1117	1117	1117
TE-21-10-3-5-3	836	2051	1126	1579	2051	847	1128	1128	1128	1128
TE-21-10-4-5-3	722	1859	952	1511	1859	786	1138	1138	1138	1138
TE-21-10-5-5-3	683	1677	950	1500	1677	782	1029	1029	1029	1029

Table A.25: Results for node-disjointness on TE-21-10 instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TE-21-10-1-3-1	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.00
TE-21-10-2-3-1	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01
TE-21-10-3-3-1	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01
TE-21-10-4-3-1	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00
TE-21-10-5-3-1	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.00
TE-21-10-1-3-2	1.19	0.02	0.89	0.02	0.02	0.93	0.02	0.02	0.02	0.02
TE-21-10-2-3-2	0.98	0.02	0.64	0.01	0.01	0.57	0.02	0.02	0.01	0.02
TE-21-10-3-3-2	0.73	0.02	0.49	0.02	0.01	0.45	0.02	0.02	0.02	0.02
TE-21-10-4-3-2	0.98	0.02	0.88	0.02	0.01	0.77	0.02	0.02	0.01	0.02
TE-21-10-5-3-2	0.70	0.02	0.53	0.01	0.02	0.37	0.02	0.02	0.01	0.02
TE-21-10-1-3-3	1.41	0.02	1.11	0.02	0.01	1.12	0.03	0.02	0.02	0.03
TE-21-10-2-3-3	1.23	0.02	1.03	0.02	0.01	0.89	0.03	0.02	0.03	0.03
TE-21-10-3-3-3	0.90	0.02	0.73	0.02	0.01	0.65	0.03	0.01	0.02	0.02
TE-21-10-4-3-3	1.14	0.01	1.08	0.03	0.02	0.81	0.02	0.02	0.03	0.02
TE-21-10-5-3-3	0.89	0.02	0.70	0.02	0.02	0.61	0.03	0.02	0.01	0.02
TE-21-10-1-4-1	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.00
TE-21-10-2-4-1	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00
TE-21-10-3-4-1	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01
TE-21-10-4-4-1	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01
TE-21-10-5-4-1	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02
TE-21-10-1-4-2	0.89	0.02	0.60	0.02	0.01	0.50	0.01	0.02	0.02	0.02
TE-21-10-2-4-2	0.85	0.01	0.50	0.02	0.02	0.46	0.03	0.01	0.02	0.02
TE-21-10-3-4-2	0.55	0.02	0.37	0.03	0.03	0.35	0.02	0.03	0.02	0.02
TE-21-10-4-4-2	1.11	0.02	0.74	0.02	0.02	0.48	0.02	0.01	0.02	0.02
TE-21-10-5-4-2	0.79	0.01	0.51	0.02	0.01	0.35	0.02	0.01	0.01	0.02
TE-21-10-1-4-3	1.78	0.02	1.01	0.02	0.02	0.96	0.02	0.02	0.02	0.03
TE-21-10-2-4-3	1.24	0.02	1.06	0.03	0.02	0.70	0.03	0.03	0.03	0.02
TE-21-10-3-4-3	1.02	0.01	0.66	0.02	0.01	0.61	0.03	0.03	0.02	0.02
TE-21-10-4-4-3	1.22	0.02	1.03	0.03	0.01	0.72	0.02	0.02	0.02	0.03
TE-21-10-5-4-3	1.00	0.02	0.83	0.02	0.01	0.68	0.02	0.03	0.03	0.03
TE-21-10-1-5-1	0.01	0.02	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.02
TE-21-10-2-5-1	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.00
TE-21-10-3-5-1	0.01	0.01	0.01	0.01	0.01	0.02	0.00	0.01	0.01	0.01
TE-21-10-4-5-1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.00	0.01
TE-21-10-5-5-1	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01
TE-21-10-1-5-2	1.18	0.02	0.59	0.02	0.01	0.52	0.02	0.03	0.02	0.03
TE-21-10-2-5-2	0.62	0.02	0.45	0.03	0.01	0.35	0.02	0.02	0.03	0.03
TE-21-10-3-5-2	0.70	0.02	0.40	0.02	0.02	0.42	0.03	0.02	0.03	0.02
TE-21-10-4-5-2	1.47	0.02	0.87	0.02	0.02	0.39	0.03	0.02	0.02	0.02
TE-21-10-5-5-2	0.67	0.01	0.45	0.02	0.02	0.31	0.02	0.02	0.03	0.03
TE-21-10-1-5-3	2.58	0.02	2.48	0.02	0.02	1.50	0.04	0.03	0.03	0.04
TE-21-10-2-5-3	1.24	0.03	1.13	0.03	0.02	0.71	0.03	0.03	0.04	0.02
TE-21-10-3-5-3	1.48	0.02	0.82	0.04	0.02	0.64	0.03	0.03	0.03	0.03
TE-21-10-4-5-3	1.69	0.02	1.17	0.04	0.02	0.73	0.03	0.03	0.03	0.03
TE-21-10-5-5-3	1.61	0.02	1.18	0.03	0.02	0.86	0.03	0.03	0.03	0.03

Table A.26: Time consumation (s) for node-disjointness on TE-21-10 instances.

	VND with									
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TE-21-10-1-3-1	271	271	271	271	255	255	255	255	255	255
TE-21-10-2-3-1	263	263	263	263	317	317	317	317	317	317
TE-21-10-3-3-1	280	280	280	280	315	315	315	315	315	315
TE-21-10-4-3-1	271	271	271	271	285	285	285	285	285	285
TE-21-10-5-3-1	208	208	208	208	249	249	249	249	249	249
TE-21-10-1-3-2	786	634	793	598	634	824	653	653	653	653
TE-21-10-2-3-2	711	558	691	555	558	758	652	652	652	652
TE-21-10-3-3-2	637	609	683	591	609	663	579	579	579	579
TE-21-10-4-3-2	676	560	695	554	560	676	635	635	635	635
TE-21-10-5-3-2	562	462	593	462	462	604	533	533	533	533
TE-21-10-1-3-3	1113	904	1166	869	904	1178	1017	1017	1017	1017
TE-21-10-2-3-3	985	912	1012	888	912	1011	957	957	957	957
TE-21-10-3-3-3	891	884	1065	937	884	958	908	908	908	908
TE-21-10-4-3-3	919	817	903	717	817	955	825	825	825	825
TE-21-10-5-3-3	826	726	842	739	726	833	803	803	803	803
TE-21-10-1-4-1	271	271	271	271	273	273	273	273	273	273
TE-21-10-2-4-1	263	263	263	263	303	303	303	303	303	303
TE-21-10-3-4-1	280	280	280	280	285	285	285	285	285	285
TE-21-10-4-4-1	271	271	271	271	301	301	301	301	301	301
TE-21-10-5-4-1	208	208	208	208	249	249	249	249	249	249
TE-21-10-1-4-2	632	540	603	531	540	662	510	510	510	510
TE-21-10-2-4-2	598	539	639	525	539	640	589	589	589	589
TE-21-10-3-4-2	583	541	626	521	541	583	562	562	562	562
TE-21-10-4-4-2	594	472	636	479	472	594	554	554	554	554
TE-21-10-5-4-2	443	436	443	426	436	476	439	439	439	439
TE-21-10-1-4-3	898	816	949	788	816	983	916	916	916	916
TE-21-10-2-4-3	846	795	884	793	795	809	765	765	765	765
TE-21-10-3-4-3	851	820	968	806	820	884	914	914	914	914
TE-21-10-4-4-3	804	715	895	678	715	848	763	763	763	763
TE-21-10-5-4-3	665	629	889	637	629	740	695	695	695	695
TE-21-10-1-5-1	271	271	271	271	273	273	273	273	273	273
TE-21-10-2-5-1	263	263	263	263	303	303	303	303	303	303
TE-21-10-3-5-1	280	280	280	280	285	285	285	285	285	285
TE-21-10-4-5-1	271	271	271	271	307	307	307	307	307	307
TE-21-10-5-5-1	208	208	208	208	249	249	249	249	249	249
TE-21-10-1-5-2	524	511	515	523	511	495	505	505	505	505
TE-21-10-2-5-2	523	507	581	522	507	642	555	555	555	555
TE-21-10-3-5-2	532	541	528	473	541	501	512	512	512	512
TE-21-10-4-5-2	511	454	525	447	454	511	506	506	506	506
TE-21-10-5-5-2	407	385	468	385	385	407	397	397	397	397
TE-21-10-1-5-3	799	796	856	787	796	880	856	856	856	856
TE-21-10-2-5-3	810	764	763	720	764	874	695	695	695	695
TE-21-10-3-5-3	820	783	832	777	783	802	874	874	874	874
TE-21-10-4-5-3	722	699	722	678	699	683	672	672	672	672
TE-21-10-5-5-3	683	587	752	637	587	726	647	647	647	647

Table A.27: Results for node-disjointness on TE-21-10 instances.

	VND with									
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TE-21-10-1-3-1	0.16	0.16	0.16	0.16	0.15	0.16	0.16	0.16	0.16	0.16
TE-21-10-2-3-1	0.23	0.24	0.24	0.23	0.05	0.05	0.05	0.06	0.05	0.05
TE-21-10-3-3-1	0.17	0.17	0.17	0.17	0.15	0.16	0.16	0.16	0.15	0.14
TE-21-10-4-3-1	0.16	0.17	0.16	0.16	0.10	0.10	0.11	0.11	0.11	0.11
TE-21-10-5-3-1	0.19	0.28	0.29	0.29	0.17	0.16	0.16	0.16	0.17	0.17
TE-21-10-1-3-2	1.24	0.44	1.18	0.38	0.43	1.16	0.17	0.17	0.17	0.16
TE-21-10-2-3-2	1.07	0.45	0.97	0.42	0.45	0.74	0.17	0.18	0.17	0.18
TE-21-10-3-3-2	0.79	0.39	0.71	0.39	0.38	0.60	0.21	0.21	0.22	0.22
TE-21-10-4-3-2	1.05	0.43	1.17	0.40	0.43	0.98	0.12	0.13	0.12	0.13
TE-21-10-5-3-2	0.80	0.41	0.76	0.41	0.42	0.48	0.21	0.23	0.22	0.22
TE-21-10-1-3-3	1.48	0.60	1.46	0.69	0.63	1.42	0.29	0.29	0.29	0.30
TE-21-10-2-3-3	1.35	0.58	1.40	0.54	0.58	1.15	0.26	0.25	0.26	0.26
TE-21-10-3-3-3	0.97	0.67	1.16	0.54	0.67	0.84	0.27	0.27	0.27	0.27
TE-21-10-4-3-3	1.27	0.61	1.53	0.66	0.61	1.11	0.28	0.27	0.27	0.27
TE-21-10-5-3-3	0.95	0.69	1.09	0.49	0.68	0.95	0.34	0.34	0.35	0.35
TE-21-10-1-4-1	0.19	0.19	0.19	0.19	0.10	0.10	0.09	0.09	0.09	0.09
TE-21-10-2-4-1	0.24	0.24	0.24	0.24	0.06	0.06	0.06	0.07	0.07	0.07
TE-21-10-3-4-1	0.19	0.20	0.19	0.20	0.12	0.12	0.12	0.12	0.11	0.12
TE-21-10-4-4-1	0.19	0.19	0.19	0.18	0.09	0.09	0.09	0.10	0.10	0.10
TE-21-10-5-4-1	0.21	0.33	0.33	0.34	0.19	0.19	0.19	0.19	0.19	0.20
TE-21-10-1-4-2	0.95	0.55	0.99	0.50	0.55	0.75	0.25	0.26	0.26	0.26
TE-21-10-2-4-2	0.96	0.57	0.77	0.50	0.57	0.74	0.21	0.21	0.21	0.20
TE-21-10-3-4-2	0.66	0.55	0.74	0.48	0.54	0.54	0.32	0.32	0.30	0.31
TE-21-10-4-4-2	1.17	0.57	0.84	0.56	0.57	0.66	0.30	0.29	0.28	0.30
TE-21-10-5-4-2	0.93	0.59	0.92	0.64	0.58	0.57	0.33	0.33	0.33	0.33
TE-21-10-1-4-3	2.10	0.83	1.68	0.86	0.83	1.41	0.47	0.47	0.47	0.47
TE-21-10-2-4-3	1.35	0.75	1.51	0.85	0.76	1.12	0.54	0.54	0.54	0.54
TE-21-10-3-4-3	1.14	0.83	1.10	0.79	0.83	0.72	0.29	0.27	0.28	0.28
TE-21-10-4-4-3	1.32	0.89	1.36	0.88	0.89	1.18	0.42	0.42	0.43	0.43
TE-21-10-5-4-3	1.14	0.93	1.16	0.79	0.92	1.00	0.66	0.66	0.66	0.65
TE-21-10-1-5-1	0.29	0.28	0.33	0.26	0.08	0.08	0.07	0.07	0.08	0.07
TE-21-10-2-5-1	0.27	0.26	0.26	0.27	0.03	0.04	0.04	0.04	0.04	0.04
TE-21-10-3-5-1	0.22	0.22	0.22	0.22	0.13	0.13	0.13	0.13	0.13	0.14
TE-21-10-4-5-1	0.21	0.21	0.22	0.20	0.06	0.06	0.06	0.06	0.05	0.06
TE-21-10-5-5-1	0.24	0.25	0.24	0.24	0.13	0.13	0.14	0.14	0.14	0.14
TE-21-10-1-5-2	1.41	0.72	1.19	0.60	0.72	1.23	0.38	0.39	0.39	0.39
TE-21-10-2-5-2	0.97	0.69	0.78	0.63	0.69	0.51	0.35	0.35	0.36	0.35
TE-21-10-3-5-2	1.03	0.61	0.86	0.66	0.60	0.83	0.40	0.40	0.39	0.40
TE-21-10-4-5-2	1.60	0.70	1.16	0.75	0.70	0.65	0.53	0.53	0.54	0.54
TE-21-10-5-5-2	0.79	0.75	0.88	0.76	0.76	0.54	0.44	0.45	0.45	0.46
TE-21-10-1-5-3	2.61	0.99	3.09	0.99	1.00	1.86	0.59	0.58	0.59	0.59
TE-21-10-2-5-3	1.57	0.97	2.11	1.25	0.97	0.92	0.71	0.70	0.70	0.70
TE-21-10-3-5-3	1.72	0.99	1.54	1.08	0.99	0.83	0.38	0.39	0.39	0.40
TE-21-10-4-5-3	1.78	1.07	1.51	0.99	1.06	1.19	0.69	0.69	0.69	0.70
TE-21-10-5-5-3	1.67	1.18	1.78	0.90	1.17	1.13	0.86	0.86	0.79	0.85

Table A.28: Time consumation (s) for node-disjointness on TE-21-10 instances.

	MSVND with											
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TE-21-10-1-3-1	263.73	8.77	264.13	8.14	261.77	8.35	263.57	7.11	263.03	7.26	262.43	8.43
TE-21-10-2-3-1	265.03	5.47	264.37	4.85	266.17	5.63	264.30	5.05	265.67	5.49	265.27	5.63
TE-21-10-3-3-1	274.00	3.37	273.87	2.78	274.47	3.27	274.67	3.65	275.33	3.41	274.13	3.25
TE-21-10-4-3-1	258.30	5.57	257.47	6.47	257.07	5.04	254.30	5.83	254.10	5.05	257.60	5.47
TE-21-10-5-3-1	210.10	4.43	210.40	4.29	210.00	5.17	209.97	4.25	210.33	5.71	208.73	3.65
TE-21-10-1-3-2	634.00	0.00	634.00	0.00	634.00	0.00	590.53	16.51	588.70	14.97	592.70	18.38
TE-21-10-2-3-2	558.00	0.00	558.00	0.00	558.00	0.00	565.10	9.96	561.17	10.96	564.43	9.86
TE-21-10-3-3-2	609.00	0.00	609.00	0.00	609.00	0.00	576.40	19.92	579.77	20.16	586.90	18.96
TE-21-10-4-3-2	560.00	0.00	560.00	0.00	560.00	0.00	530.43	17.87	534.00	16.13	525.33	15.88
TE-21-10-5-3-2	462.00	0.00	462.00	0.00	462.00	0.00	497.50	19.37	491.40	21.46	495.40	19.27
TE-21-10-1-3-3	904.00	0.00	904.00	0.00	904.00	0.00	919.17	19.54	911.67	21.20	921.90	16.01
TE-21-10-2-3-3	912.00	0.00	912.00	0.00	912.00	0.00	855.80	25.97	856.37	24.25	863.57	30.87
TE-21-10-3-3-3	884.00	0.00	884.00	0.00	884.00	0.00	838.60	24.06	844.70	21.00	832.27	19.49
TE-21-10-4-3-3	817.00	0.00	817.00	0.00	817.00	0.00	766.67	25.17	776.23	24.14	774.90	27.11
TE-21-10-5-3-3	726.00	0.00	726.00	0.00	726.00	0.00	717.20	20.44	719.83	28.34	721.70	27.00
TE-21-10-1-4-1	263.37	8.10	266.50	8.23	263.13	8.73	265.57	8.46	264.93	7.89	266.37	9.70
TE-21-10-2-4-1	261.90	4.66	263.30	4.94	262.97	4.87	261.37	4.34	262.63	4.66	263.60	5.30
TE-21-10-3-4-1	275.67	5.90	275.43	3.65	274.23	3.77	274.73	3.77	274.47	3.42	275.00	3.22
TE-21-10-4-4-1	250.47	7.01	251.37	7.61	252.77	6.50	250.90	7.45	252.97	7.50	250.63	7.73
TE-21-10-5-4-1	211.50	5.29	211.40	4.95	211.73	6.43	213.10	5.93	211.13	5.17	212.20	6.40
TE-21-10-1-4-2	540.00	0.00	540.00	0.00	540.00	0.00	526.87	10.05	529.93	11.22	531.20	12.60
TE-21-10-2-4-2	539.00	0.00	539.00	0.00	539.00	0.00	515.30	12.59	517.50	10.59	518.20	8.84
TE-21-10-3-4-2	541.00	0.00	541.00	0.00	541.00	0.00	505.20	17.16	505.03	19.00	505.17	21.03
TE-21-10-4-4-2	472.00	0.00	472.00	0.00	472.00	0.00	478.10	16.63	481.97	11.14	479.73	15.96
TE-21-10-5-4-2	436.00	0.00	436.00	0.00	436.00	0.00	423.57	12.73	419.40	13.68	419.57	12.60
TE-21-10-1-4-3	816.00	0.00	816.00	0.00	816.00	0.00	774.30	31.73	780.37	31.05	776.73	28.74
TE-21-10-2-4-3	795.00	0.00	795.00	0.00	795.00	0.00	752.63	24.64	748.57	30.62	754.50	29.74
TE-21-10-3-4-3	820.00	0.00	820.00	0.00	820.00	0.00	763.90	23.58	752.70	22.96	761.27	24.16
TE-21-10-4-4-3	715.00	0.00	715.00	0.00	715.00	0.00	673.03	19.21	673.63	17.98	673.10	19.10
TE-21-10-5-4-3	629.00	0.00	629.00	0.00	629.00	0.00	618.83	25.12	627.33	30.36	627.53	24.23
TE-21-10-1-5-1	263.73	8.71	265.43	8.39	266.40	7.96	265.13	8.40	264.60	7.74	267.00	8.62
TE-21-10-2-5-1	261.57	4.29	261.10	4.01	263.30	5.62	261.47	4.14	261.53	4.46	260.23	3.84
TE-21-10-3-5-1	275.17	4.58	274.60	4.12	274.13	3.40	274.67	3.25	274.40	3.54	273.97	2.94
TE-21-10-4-5-1	250.77	8.38	253.30	6.92	250.43	6.48	251.23	6.11	252.50	7.38	252.63	6.37
TE-21-10-5-5-1	212.33	7.54	212.70	8.51	212.87	5.98	210.17	3.46	212.60	6.68	211.93	7.03
TE-21-10-1-5-2	511.00	0.00	511.00	0.00	511.00	0.00	492.97	10.45	487.90	10.95	487.10	11.89
TE-21-10-2-5-2	507.00	0.00	507.00	0.00	507.00	0.00	473.80	8.02	476.57	16.48	476.77	10.87
TE-21-10-3-5-2	541.00	0.00	541.00	0.00	541.00	0.00	478.77	18.81	470.10	18.45	466.43	15.84
TE-21-10-4-5-2	454.00	0.00	454.00	0.00	454.00	0.00	433.80	20.14	436.30	18.92	438.83	9.65
TE-21-10-5-5-2	385.00	0.00	385.00	0.00	385.00	0.00	386.97	9.05	391.50	11.43	387.97	8.56
TE-21-10-1-5-3	796.00	0.00	796.00	0.00	796.00	0.00	730.33	28.17	725.83	34.86	721.00	26.62
TE-21-10-2-5-3	764.00	0.00	764.00	0.00	764.00	0.00	709.47	17.98	703.97	19.77	710.00	20.01
TE-21-10-3-5-3	783.00	0.00	783.00	0.00	783.00	0.00	722.80	24.58	720.93	22.86	714.27	16.31
TE-21-10-4-5-3	699.00	0.00	699.00	0.00	699.00	0.00	630.93	14.15	636.00	18.99	635.07	19.11
TE-21-10-5-5-3	587.00	0.00	587.00	0.00	587.00	0.00	604.20	23.09	598.73	25.81	598.70	24.65

Table A.29: Results for node-disjointness on TE-21-10 instances.

	MSVND with											
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TE-21-10-1-3-1	0.98	0.08	1.02	0.08	1.01	0.09	1.00	0.07	1.03	0.06	1.03	0.07
TE-21-10-2-3-1	1.11	0.10	1.10	0.09	1.12	0.13	1.11	0.09	1.13	0.10	1.11	0.09
TE-21-10-3-3-1	0.99	0.08	1.01	0.08	1.03	0.11	1.20	0.24	1.24	0.28	1.12	0.18
TE-21-10-4-3-1	0.94	0.10	1.00	0.10	0.98	0.10	1.04	0.08	1.01	0.09	0.95	0.10
TE-21-10-5-3-1	1.47	0.27	1.19	0.18	1.16	0.18	1.10	0.07	1.08	0.05	1.09	0.06
TE-21-10-1-3-2	3.99	0.40	3.93	0.17	3.89	0.01	1.60	0.11	1.64	0.13	1.62	0.13
TE-21-10-2-3-2	4.15	0.01	4.15	0.01	4.15	0.01	1.73	0.24	1.69	0.14	1.71	0.17
TE-21-10-3-3-2	3.58	0.17	3.62	0.29	4.56	0.69	2.01	0.35	1.93	0.29	1.93	0.24
TE-21-10-4-3-2	3.90	0.01	3.90	0.01	3.90	0.01	1.67	0.13	1.73	0.38	1.68	0.16
TE-21-10-5-3-2	3.83	0.01	3.83	0.02	3.83	0.02	1.82	0.15	1.82	0.17	1.85	0.15
TE-21-10-1-3-3	5.67	0.01	5.68	0.01	5.68	0.01	2.57	0.16	2.63	0.21	2.58	0.18
TE-21-10-2-3-3	5.35	0.32	5.37	0.32	5.24	0.01	2.95	0.29	2.89	0.29	2.85	0.28
TE-21-10-3-3-3	6.03	0.01	6.03	0.01	6.03	0.01	3.12	0.26	3.10	0.23	3.09	0.32
TE-21-10-4-3-3	5.80	0.79	5.86	0.79	5.85	0.67	2.98	0.26	3.03	0.29	2.95	0.29
TE-21-10-5-3-3	6.25	0.23	6.24	0.14	6.26	0.40	3.34	0.18	3.30	0.23	3.28	0.19
TE-21-10-1-4-1	0.88	0.07	0.89	0.07	0.89	0.08	0.91	0.06	0.90	0.07	0.90	0.07
TE-21-10-2-4-1	1.06	0.07	1.06	0.08	1.08	0.09	1.06	0.10	1.07	0.08	1.07	0.08
TE-21-10-3-4-1	0.95	0.07	0.96	0.08	0.96	0.08	0.98	0.07	0.98	0.06	0.97	0.06
TE-21-10-4-4-1	0.89	0.07	0.86	0.08	0.89	0.06	0.90	0.08	0.89	0.09	0.89	0.07
TE-21-10-5-4-1	1.40	0.21	1.33	0.27	1.16	0.22	1.34	0.23	1.24	0.22	1.01	0.07
TE-21-10-1-4-2	4.91	0.01	4.98	0.31	4.95	0.15	2.49	0.26	2.51	0.16	2.47	0.12
TE-21-10-2-4-2	5.17	0.01	5.16	0.01	5.23	0.20	2.72	0.23	2.64	0.22	2.68	0.35
TE-21-10-3-4-2	4.93	0.01	4.93	0.01	4.92	0.01	2.82	0.19	2.79	0.16	2.78	0.17
TE-21-10-4-4-2	5.17	0.01	5.17	0.01	5.17	0.01	2.53	0.19	2.51	0.17	2.55	0.16
TE-21-10-5-4-2	5.22	0.01	5.22	0.01	5.23	0.01	2.88	0.22	2.93	0.22	2.94	0.24
TE-21-10-1-4-3	7.44	0.01	7.45	0.01	7.45	0.01	4.46	0.23	4.40	0.29	6.46	1.01
TE-21-10-2-4-3	7.60	1.14	6.82	0.03	6.80	0.01	4.73	0.32	4.52	0.28	4.63	0.30
TE-21-10-3-4-3	7.46	0.01	7.46	0.01	7.45	0.01	4.39	0.35	4.43	0.21	4.34	0.42
TE-21-10-4-4-3	8.03	0.01	8.03	0.01	8.02	0.01	4.55	0.32	4.62	0.34	4.51	0.37
TE-21-10-5-4-3	8.30	0.01	8.30	0.01	8.31	0.02	5.02	0.34	4.91	0.31	4.93	0.25
TE-21-10-1-5-1	0.94	0.14	1.02	0.22	1.02	0.15	1.24	0.28	1.08	0.23	0.93	0.08
TE-21-10-2-5-1	1.14	0.09	1.13	0.09	1.13	0.11	1.16	0.08	1.15	0.10	1.13	0.08
TE-21-10-3-5-1	1.03	0.07	1.04	0.08	1.05	0.09	1.03	0.06	1.06	0.07	1.04	0.08
TE-21-10-4-5-1	0.89	0.10	0.82	0.11	0.85	0.08	0.90	0.07	0.85	0.10	0.87	0.08
TE-21-10-5-5-1	1.03	0.08	1.05	0.06	1.03	0.05	1.03	0.07	1.03	0.06	1.03	0.06
TE-21-10-1-5-2	6.46	0.01	6.46	0.01	6.46	0.01	3.46	0.24	3.43	0.19	3.44	0.18
TE-21-10-2-5-2	6.27	0.02	6.27	0.01	6.27	0.01	3.70	0.23	3.69	0.20	3.69	0.26
TE-21-10-3-5-2	5.48	0.01	5.50	0.03	5.54	0.03	3.74	0.25	3.67	0.27	3.72	0.26
TE-21-10-4-5-2	6.29	0.01	6.29	0.01	6.29	0.01	3.55	0.25	3.52	0.22	3.55	0.23
TE-21-10-5-5-2	6.82	0.03	6.90	0.37	7.64	0.90	4.08	0.41	4.40	0.62	4.78	1.15
TE-21-10-1-5-3	8.94	0.02	8.93	0.01	8.93	0.02	5.56	0.30	5.57	0.37	5.53	0.37
TE-21-10-2-5-3	8.77	0.02	8.77	0.01	8.78	0.01	6.16	0.45	6.13	0.36	6.19	0.39
TE-21-10-3-5-3	8.97	0.02	9.01	0.08	10.13	1.64	6.53	0.72	5.66	0.42	5.47	0.23
TE-21-10-4-5-3	9.64	0.01	9.64	0.01	9.65	0.02	5.76	0.33	6.49	0.53	8.80	0.63
TE-21-10-5-5-3	10.57	0.05	10.56	0.03	10.64	0.04	6.01	0.28	5.88	0.42	5.93	0.41

Table A.30: Time consumation (s) for node-disjointness on TE-21-10 instances.

	GRASP											
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TE-21-10-1-3-1	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00
TE-21-10-2-3-1	263.00	0.00	263.00	0.00	263.00	0.00	263.00	0.00	263.00	0.00	263.00	0.00
TE-21-10-3-3-1	280.00	0.00	280.00	0.00	280.00	0.00	280.00	0.00	280.00	0.00	280.00	0.00
TE-21-10-4-3-1	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00
TE-21-10-5-3-1	208.00	0.00	208.00	0.00	208.00	0.00	208.00	0.00	208.00	0.00	208.00	0.00
TE-21-10-1-3-2	756.03	9.12	755.60	41.84	727.57	43.90	760.63	76.95	781.37	58.08	787.27	69.17
TE-21-10-2-3-2	693.80	21.92	673.03	29.10	674.20	37.68	683.33	56.26	736.87	56.92	750.97	92.32
TE-21-10-3-3-2	629.10	16.19	639.03	23.54	673.50	35.32	724.43	64.29	793.93	94.90	787.07	89.67
TE-21-10-4-3-2	629.97	22.33	615.33	38.87	624.67	33.44	644.33	53.66	709.17	93.85	697.50	71.98
TE-21-10-5-3-2	556.20	25.04	555.23	29.69	568.57	26.08	593.57	37.58	683.03	86.71	723.70	103.59
TE-21-10-1-3-3	1131.00	15.93	1084.63	46.92	1101.93	57.76	1084.40	56.19	1119.43	87.87	1154.83	104.87
TE-21-10-2-3-3	999.70	32.84	998.97	30.57	996.13	37.86	1018.13	49.62	1079.03	102.15	1105.60	107.09
TE-21-10-3-3-3	906.03	7.01	951.07	35.67	1002.77	52.09	1031.43	56.18	1115.27	106.55	1168.57	93.31
TE-21-10-4-3-3	929.83	24.18	920.40	45.30	895.40	55.10	941.10	65.99	988.13	87.72	1020.43	115.21
TE-21-10-5-3-3	801.43	19.72	808.43	22.69	836.47	38.81	893.83	66.52	990.77	103.37	1010.97	125.43
TE-21-10-1-4-1	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00
TE-21-10-2-4-1	263.00	0.00	263.00	0.00	263.00	0.00	263.00	0.00	263.00	0.00	263.00	0.00
TE-21-10-3-4-1	280.00	0.00	280.00	0.00	280.00	0.00	280.00	0.00	280.00	0.00	280.00	0.00
TE-21-10-4-4-1	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00
TE-21-10-5-4-1	208.00	0.00	208.00	0.00	208.00	0.00	208.00	0.00	208.00	0.00	208.00	0.00
TE-21-10-1-4-2	610.83	38.56	625.03	33.56	630.30	44.67	734.00	81.69	753.93	75.22	765.17	94.02
TE-21-10-2-4-2	592.40	18.60	595.70	27.69	637.90	45.50	699.10	63.67	726.83	96.16	772.50	77.98
TE-21-10-3-4-2	564.63	25.99	586.53	40.03	630.20	55.57	730.20	81.96	787.47	94.94	824.60	117.95
TE-21-10-4-4-2	565.50	19.59	553.63	25.11	586.13	46.14	641.33	79.66	678.60	97.50	712.97	101.90
TE-21-10-5-4-2	433.03	22.30	458.03	34.86	520.47	48.56	576.17	65.53	700.90	119.67	707.67	102.63
TE-21-10-1-4-3	910.30	45.61	921.87	49.88	938.73	75.11	1068.77	105.58	1167.80	132.21	1136.13	116.48
TE-21-10-2-4-3	838.37	20.91	877.80	41.36	926.40	50.56	1020.57	85.64	1067.60	103.93	1068.27	106.41
TE-21-10-3-4-3	868.77	20.66	878.27	35.84	911.37	60.00	1037.40	75.74	1136.27	142.24	1170.90	112.92
TE-21-10-4-4-3	771.60	24.15	794.73	40.55	842.63	60.98	916.60	75.32	964.47	87.90	1035.83	113.65
TE-21-10-5-4-3	691.27	27.00	697.53	28.03	750.53	45.08	848.87	87.99	984.57	113.94	1032.07	148.45
TE-21-10-1-5-1	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00
TE-21-10-2-5-1	263.00	0.00	263.00	0.00	263.00	0.00	263.00	0.00	263.00	0.00	263.00	0.00
TE-21-10-3-5-1	280.00	0.00	280.00	0.00	280.00	0.00	280.00	0.00	280.00	0.00	280.00	0.00
TE-21-10-4-5-1	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00
TE-21-10-5-5-1	208.00	0.00	208.00	0.00	208.00	0.00	208.00	0.00	208.00	0.00	208.00	0.00
TE-21-10-1-5-2	520.00	8.86	579.77	33.42	622.37	59.46	740.10	107.93	769.93	100.43	763.53	108.75
TE-21-10-2-5-2	513.03	12.29	544.07	30.73	620.53	63.25	692.27	86.65	733.20	78.07	740.57	94.20
TE-21-10-3-5-2	515.43	11.57	544.87	27.76	601.53	45.71	709.67	101.02	824.73	114.15	793.90	129.32
TE-21-10-4-5-2	506.33	11.73	512.23	25.94	558.60	48.13	642.03	68.49	683.83	107.88	696.47	91.03
TE-21-10-5-5-2	402.20	5.98	428.87	27.21	482.40	45.19	581.67	63.44	655.63	105.85	690.73	107.02
TE-21-10-1-5-3	788.30	16.26	855.20	41.00	912.80	61.41	1092.93	153.59	1076.83	94.20	1114.13	130.94
TE-21-10-2-5-3	796.03	29.38	810.17	48.92	867.00	76.61	980.87	88.92	1068.03	115.93	1096.87	99.83
TE-21-10-3-5-3	832.20	24.62	817.27	42.06	901.97	71.67	1023.27	96.44	1109.20	115.00	1150.77	152.34
TE-21-10-4-5-3	695.20	15.82	707.13	36.53	805.43	72.31	925.23	101.64	996.40	128.32	996.80	143.97
TE-21-10-5-5-3	677.33	8.15	678.33	34.49	720.07	59.80	842.47	100.93	990.80	130.32	982.20	163.66

Table A.31: Results for node-disjointness on TE-21-10 instances.

	GRASP											
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TE-21-10-1-3-1	0.16	0.01	0.16	0.00	0.16	0.01	0.16	0.00	0.16	0.01	0.16	0.01
TE-21-10-2-3-1	0.23	0.01	0.23	0.01	0.23	0.01	0.23	0.01	0.23	0.01	0.23	0.00
TE-21-10-3-3-1	0.17	0.01	0.17	0.00	0.18	0.01	0.17	0.01	0.17	0.00	0.17	0.01
TE-21-10-4-3-1	0.16	0.00	0.16	0.00	0.16	0.00	0.16	0.01	0.16	0.01	0.16	0.00
TE-21-10-5-3-1	0.19	0.03	0.28	0.02	0.28	0.01	0.26	0.02	0.29	0.01	0.29	0.01
TE-21-10-1-3-2	1.22	0.04	1.21	0.17	1.19	0.32	0.72	0.15	0.76	0.18	0.60	0.13
TE-21-10-2-3-2	1.12	0.05	1.20	0.13	1.01	0.23	0.75	0.13	0.68	0.17	0.63	0.13
TE-21-10-3-3-2	0.87	0.05	0.85	0.12	0.96	0.19	0.74	0.16	0.73	0.18	0.68	0.15
TE-21-10-4-3-2	1.06	0.06	0.97	0.13	0.81	0.20	0.71	0.14	0.66	0.11	0.66	0.15
TE-21-10-5-3-2	0.76	0.05	0.79	0.12	0.78	0.17	0.72	0.16	0.65	0.17	0.64	0.18
TE-21-10-1-3-3	1.53	0.04	1.52	0.13	1.51	0.23	1.10	0.29	0.99	0.16	0.96	0.16
TE-21-10-2-3-3	1.44	0.11	1.52	0.13	1.39	0.28	1.10	0.23	1.06	0.16	0.99	0.17
TE-21-10-3-3-3	1.06	0.04	1.16	0.13	1.29	0.22	1.04	0.19	1.02	0.20	1.05	0.26
TE-21-10-4-3-3	1.18	0.07	1.19	0.17	1.15	0.20	1.01	0.21	0.99	0.23	1.13	0.28
TE-21-10-5-3-3	0.97	0.06	1.06	0.15	1.07	0.15	1.04	0.24	0.99	0.22	1.03	0.25
TE-21-10-1-4-1	0.19	0.00	0.19	0.00	0.19	0.01	0.19	0.00	0.19	0.01	0.19	0.00
TE-21-10-2-4-1	0.24	0.00	0.24	0.01	0.24	0.00	0.24	0.01	0.24	0.00	0.24	0.01
TE-21-10-3-4-1	0.20	0.00	0.20	0.01	0.20	0.01	0.20	0.01	0.20	0.00	0.20	0.00
TE-21-10-4-4-1	0.19	0.00	0.19	0.00	0.19	0.01	0.19	0.00	0.19	0.00	0.19	0.00
TE-21-10-5-4-1	0.28	0.06	0.23	0.02	0.22	0.01	0.22	0.01	0.21	0.01	0.22	0.01
TE-21-10-1-4-2	1.05	0.09	1.15	0.15	1.03	0.34	0.70	0.14	0.72	0.18	0.64	0.19
TE-21-10-2-4-2	0.99	0.10	1.43	0.29	0.85	0.27	0.74	0.15	0.69	0.19	0.68	0.21
TE-21-10-3-4-2	0.76	0.08	0.82	0.11	0.71	0.12	0.70	0.16	0.68	0.19	0.67	0.11
TE-21-10-4-4-2	1.23	0.07	1.03	0.18	0.77	0.20	0.66	0.21	0.71	0.19	0.65	0.14
TE-21-10-5-4-2	0.98	0.07	0.77	0.13	0.62	0.12	0.73	0.19	0.65	0.21	0.71	0.16
TE-21-10-1-4-3	3.18	0.18	1.90	0.37	1.94	0.42	1.35	0.46	1.18	0.33	1.10	0.28
TE-21-10-2-4-3	1.43	0.16	1.60	0.34	1.33	0.43	1.26	0.35	1.13	0.29	1.13	0.25
TE-21-10-3-4-3	1.04	0.06	1.20	0.21	1.10	0.20	1.28	0.46	1.12	0.29	1.20	0.27
TE-21-10-4-4-3	1.40	0.12	1.46	0.23	1.21	0.26	1.16	0.32	1.09	0.19	1.07	0.30
TE-21-10-5-4-3	1.13	0.07	1.03	0.17	1.06	0.20	1.19	0.39	1.02	0.23	1.09	0.28
TE-21-10-1-5-1	0.21	0.01	0.21	0.01	0.21	0.01	0.22	0.01	0.21	0.01	0.21	0.01
TE-21-10-2-5-1	0.27	0.00	0.27	0.00	0.27	0.01	0.27	0.00	0.27	0.00	0.27	0.00
TE-21-10-3-5-1	0.22	0.01	0.22	0.00	0.22	0.01	0.22	0.01	0.22	0.01	0.23	0.01
TE-21-10-4-5-1	0.21	0.01	0.21	0.01	0.21	0.01	0.21	0.00	0.21	0.00	0.21	0.00
TE-21-10-5-5-1	0.24	0.01	0.24	0.00	0.24	0.01	0.24	0.01	0.24	0.01	0.24	0.01
TE-21-10-1-5-2	1.43	0.07	1.46	0.21	1.14	0.38	0.77	0.23	0.85	0.28	0.91	0.30
TE-21-10-2-5-2	0.95	0.06	1.05	0.15	1.01	0.41	0.77	0.20	0.75	0.19	0.80	0.19
TE-21-10-3-5-2	1.02	0.12	0.98	0.18	0.80	0.24	0.89	0.33	0.80	0.25	0.84	0.25
TE-21-10-4-5-2	1.52	0.07	1.39	0.21	0.88	0.27	0.80	0.24	0.76	0.18	0.75	0.23
TE-21-10-5-5-2	0.73	0.05	0.82	0.14	0.79	0.20	0.89	0.22	1.21	0.33	1.32	0.46
TE-21-10-1-5-3	3.16	0.23	2.95	0.83	1.86	0.40	1.27	0.40	1.42	0.37	1.38	0.43
TE-21-10-2-5-3	1.34	0.14	1.83	0.42	1.72	0.56	1.33	0.34	1.45	0.40	1.31	0.29
TE-21-10-3-5-3	1.55	0.20	1.45	0.27	1.30	0.33	1.50	0.47	1.34	0.43	1.45	0.68
TE-21-10-4-5-3	2.15	0.16	2.20	0.40	1.47	0.36	1.43	0.44	1.42	0.42	1.40	0.45
TE-21-10-5-5-3	1.58	0.20	1.28	0.34	1.22	0.22	1.27	0.23	1.29	0.45	1.34	0.34

Table A.32: Time consumation (s) for node-disjointness on TE-21-10 instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
dfn-gwin-3-1	59216	59216	59216	59216	15684	15684	15684	15684	15684	15684
dfn-gwin-3-2	19932	74936	27432	74936	74936	27432	26600	26600	26600	26600
dfn-gwin-4-1	47360	47360	47360	47360	13964	13964	13964	13964	13964	13964
dfn-gwin-4-2	19284	74936	21104	74936	74936	21104	20464	20464	20464	20464
dfn-gwin-5-1	47360	47360	47360	47360	10552	10552	10552	10552	10552	10552
dfn-gwin-5-2	16692	74936	16692	74936	74936	16692	19212	19212	19212	19212
di-yuan-3-1	803900	803900	803900	803900	575200	575200	575200	575200	575200	575200
di-yuan-3-2	713900	2011300	976300	1381400	2011300	866200	861200	861200	861200	861200
di-yuan-3-3	1009700	2474200	1203100	2356400	2474200	1157800	1232500	1232500	1232500	1232500
di-yuan-4-1	695900	695900	695900	695900	397400	397400	397400	397400	397400	397400
di-yuan-4-2	581100	2011300	689600	1531400	2011300	653900	644300	644300	644300	644300
di-yuan-4-3	783500	2474200	1005200	2356400	2474200	930800	1033300	1033300	1033300	1033300
di-yuan-5-1	695900	695900	695900	695900	313400	313400	313400	313400	313400	313400
di-yuan-5-2	494500	2011300	604300	1531400	2011300	559300	595800	595800	595800	595800
di-yuan-5-3	718600	2474200	959900	2356400	2474200	836600	1001000	1001000	1001000	1001000
nobel-us-3-1	189130	189130	189130	189130	189130	189130	189130	189130	189130	189130
nobel-us-4-1	189130	189130	189130	189130	163770	163770	163770	163770	163770	163770
nobel-us-5-1	189130	189130	189130	189130	127800	127800	127800	127800	127800	127800
nobel-us-5-2	169070	189130	189130	189130	189130	182110	189130	189130	189130	189130
pdh-3-1	2712178	2712178	2712178	2712178	1161941	1161941	1161941	1161941	1161941	1161941
pdh-3-2	1874780	3400028	2215834	3034152	3400028	2102856	2174141	2174141	2174141	2174141
pdh-3-3	2440112	4210043	3177340	3331128	4210043	3177340	3019241	3019241	3019241	3019241
pdh-4-1	2712178	2712178	2712178	2712178	1092414	1092414	1092414	1092414	1092414	1092414
pdh-4-2	1769088	3400028	2079006	3034152	3400028	2079006	2028568	2028568	2028568	2028568
pdh-4-3	2112539	4210043	2744861	3331128	4210043	2631088	2991946	2991946	2991946	2991946
pdh-5-1	2712178	2712178	2712178	2712178	1008398	1008398	1008398	1008398	1008398	1008398
pdh-5-2	1521083	3400028	1821780	3034152	3400028	1707742	1922215	1922215	1922215	1922215
pdh-5-3	1947467	4210043	2615453	3331128	4210043	2501680	2867308	2867308	2867308	2867308
polska-4-1	4125	4125	4125	4125	3820	3820	3820	3820	3820	3820
polska-5-1	4125	4125	4125	4125	2930	2930	2930	2930	2930	2930
polska-5-2	3761	4125	4125	4125	4125	4125	4125	4125	4125	4125

Table A.33: Results for node-disjointness on SNDlib instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
dfn-gwin-3-1	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
dfn-gwin-3-2	0.45	0.04	0.37	0.03	0.03	0.31	0.03	0.03	0.03	0.03
dfn-gwin-4-1	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02
dfn-gwin-4-2	0.36	0.04	0.35	0.03	0.04	0.33	0.03	0.04	0.04	0.04
dfn-gwin-5-1	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00
dfn-gwin-5-2	0.37	0.10	0.43	0.04	0.10	0.42	0.04	0.04	0.04	0.04
di-yuan-3-1	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00
di-yuan-3-2	0.20	0.01	0.16	0.01	0.01	0.14	0.00	0.01	0.01	0.01
di-yuan-3-3	0.32	0.01	0.26	0.00	0.00	0.22	0.01	0.02	0.01	0.00
di-yuan-4-1	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
di-yuan-4-2	0.22	0.02	0.16	0.00	0.01	0.13	0.01	0.01	0.01	0.01
di-yuan-4-3	0.31	0.01	0.29	0.02	0.01	0.21	0.01	0.01	0.01	0.02
di-yuan-5-1	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
di-yuan-5-2	0.26	0.01	0.19	0.01	0.02	0.13	0.01	0.01	0.02	0.02
di-yuan-5-3	0.30	0.02	0.33	0.02	0.01	0.19	0.02	0.01	0.02	0.01
nobel-us-3-1	0.03	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01
nobel-us-4-1	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.03	0.03	0.03
nobel-us-5-1	0.07	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.04	0.04
nobel-us-5-2	0.17	0.06	0.58	0.06	0.07	0.55	0.06	0.06	0.06	0.06
pdh-3-1	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
pdh-3-2	0.15	0.01	0.10	0.01	0.01	0.08	0.01	0.01	0.01	0.01
pdh-3-3	0.23	0.02	0.15	0.01	0.00	0.15	0.01	0.01	0.01	0.01
pdh-4-1	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pdh-4-2	0.22	0.01	0.11	0.01	0.02	0.12	0.01	0.01	0.01	0.01
pdh-4-3	0.24	0.01	0.20	0.01	0.01	0.21	0.01	0.02	0.02	0.01
pdh-5-1	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
pdh-5-2	0.10	0.01	0.12	0.01	0.00	0.13	0.02	0.02	0.01	0.01
pdh-5-3	0.28	0.01	0.22	0.01	0.02	0.26	0.02	0.01	0.01	0.01
polska-4-1	0.03	0.02	0.01	0.02	0.02	0.02	0.02	0.01	0.02	0.01
polska-5-1	0.04	0.03	0.02	0.02	0.03	0.01	0.02	0.02	0.03	0.02
polska-5-2	0.12	0.03	0.19	0.03	0.03	0.22	0.03	0.03	0.03	0.02

Table A.34: Time consumation (s) for node-disjointness on SNDlib instances.

	VND with									
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
dfn-gwin-3-1	12892	12892	12892	12892	12172	12172	12172	12172	12172	12172
dfn-gwin-3-2	19932	35120	27432	36236	35120	26328	26600	26600	26600	26600
dfn-gwin-4-1	9952	9952	9952	9952	10712	10712	10712	10712	10712	10712
dfn-gwin-4-2	19284	32532	21104	31268	32532	20000	20464	20464	20464	20464
dfn-gwin-5-1	9952	9952	9952	9952	9288	9288	9288	9288	9288	9288
dfn-gwin-5-2	16692	32532	16692	26572	32532	16692	19212	19212	19212	19212
di-yuan-3-1	304100	304100	304100	304100	375200	375200	375200	375200	375200	375200
di-yuan-3-2	713900	1200500	881000	1014000	1200500	866200	798600	798600	798600	798600
di-yuan-3-3	1009700	1553000	1203100	1569100	1553000	1113600	1178100	1178100	1178100	1178100
di-yuan-4-1	304100	304100	304100	304100	308400	308400	308400	308400	308400	308400
di-yuan-4-2	581100	1100700	653900	850400	1100700	653900	644300	644300	644300	644300
di-yuan-4-3	783500	1461800	959900	1329000	1461800	890800	1004200	1004200	1004200	1004200
di-yuan-5-1	304100	304100	304100	304100	285400	285400	285400	285400	285400	285400
di-yuan-5-2	494500	929800	604300	770400	929800	559300	595800	595800	595800	595800
di-yuan-5-3	718600	1386800	959900	1329000	1386800	836600	991900	991900	991900	991900
nobel-us-3-1	169070	169070	169070	169070	165060	165060	165060	165060	165060	165060
nobel-us-4-1	169070	169070	169070	169070	163770	163770	163770	163770	163770	163770
nobel-us-5-1	169070	169070	169070	169070	121640	121640	121640	121640	121640	121640
nobel-us-5-2	169070	189130	189130	189130	189130	182110	189130	189130	189130	189130
pdh-3-1	1116079	1116079	1116079	1116079	1021403	1021403	1021403	1021403	1021403	1021403
pdh-3-2	1874780	2110983	2215834	2265124	2110983	2102856	2174141	2174141	2174141	2174141
pdh-3-3	2440112	2984244	3026997	3026997	2984244	3177340	3019241	3019241	3019241	3019241
pdh-4-1	1022676	1022676	1022676	1022676	1092414	1092414	1092414	1092414	1092414	1092414
pdh-4-2	1769088	2068053	2079006	1982193	2068053	1976363	2024063	2024063	2024063	2024063
pdh-4-3	2112539	2719333	2744861	3026997	2719333	2631088	2991946	2991946	2991946	2991946
pdh-5-1	1022676	1022676	1022676	1022676	1008398	1008398	1008398	1008398	1008398	1008398
pdh-5-2	1521083	2159831	1821780	1982193	2159831	1707742	1826542	1826542	1826542	1826542
pdh-5-3	1947467	2702903	2501680	2744861	2702903	2501680	2867308	2867308	2867308	2867308
polska-4-1	2693	2693	2693	2693	2767	2767	2767	2767	2767	2767
polska-5-1	2693	2693	2693	2693	2693	2693	2693	2693	2693	2693
polska-5-2	3761	4125	4125	4125	4125	4125	4125	4125	4125	4125

Table A.35: Results for node-disjointness on SNDlib instances.

	VND with									
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
dfn-gwin-3-1	1.23	1.20	1.20	1.22	0.21	0.21	0.21	0.21	0.22	0.21
dfn-gwin-3-2	0.54	2.59	0.46	2.23	2.61	0.50	0.11	0.10	0.11	0.11
dfn-gwin-4-1	1.14	1.12	1.12	1.12	0.23	0.22	0.22	0.22	0.22	0.22
dfn-gwin-4-2	0.44	2.94	0.45	2.57	2.92	0.53	0.13	0.12	0.12	0.12
dfn-gwin-5-1	0.54	0.85	0.98	1.05	0.11	0.12	0.12	0.12	0.13	0.12
dfn-gwin-5-2	0.44	3.53	0.52	3.57	3.50	0.53	0.14	0.13	0.13	0.14
di-yuan-3-1	0.15	0.14	0.15	0.15	0.13	0.13	0.12	0.12	0.12	0.12
di-yuan-3-2	0.23	0.46	0.25	0.21	0.46	0.18	0.10	0.11	0.11	0.09
di-yuan-3-3	0.36	0.49	0.30	0.43	0.48	0.30	0.14	0.15	0.15	0.15
di-yuan-4-1	0.12	0.11	0.11	0.11	0.06	0.07	0.07	0.07	0.07	0.06
di-yuan-4-2	0.25	0.49	0.24	0.35	0.49	0.16	0.05	0.04	0.04	0.04
di-yuan-4-3	0.36	0.62	0.36	0.63	0.62	0.30	0.10	0.11	0.10	0.11
di-yuan-5-1	0.13	0.13	0.13	0.12	0.04	0.04	0.04	0.04	0.05	0.05
di-yuan-5-2	0.31	0.58	0.22	0.42	0.59	0.18	0.04	0.04	0.05	0.04
di-yuan-5-3	0.35	0.70	0.37	0.70	0.70	0.23	0.12	0.12	0.12	0.12
nobel-us-3-1	0.31	0.28	0.29	0.29	0.39	0.38	0.49	0.62	0.62	0.62
nobel-us-4-1	0.37	0.35	0.33	0.34	0.13	0.13	0.13	0.13	0.13	0.13
nobel-us-5-1	0.41	0.38	0.37	0.37	0.28	0.28	0.28	0.28	0.27	0.27
nobel-us-5-2	0.63	0.30	0.88	0.26	0.30	0.81	0.26	0.26	0.27	0.26
pdh-3-1	0.21	0.20	0.21	0.20	0.05	0.05	0.05	0.05	0.04	0.04
pdh-3-2	0.20	0.43	0.11	0.29	0.42	0.11	0.04	0.04	0.03	0.03
pdh-3-3	0.26	0.34	0.22	0.13	0.34	0.18	0.05	0.05	0.05	0.04
pdh-4-1	0.24	0.23	0.22	0.23	0.01	0.02	0.02	0.02	0.02	0.03
pdh-4-2	0.26	0.46	0.13	0.35	0.47	0.18	0.09	0.09	0.09	0.09
pdh-4-3	0.28	0.47	0.24	0.14	0.47	0.26	0.05	0.05	0.05	0.05
pdh-5-1	0.25	0.24	0.24	0.24	0.02	0.02	0.02	0.02	0.02	0.02
pdh-5-2	0.15	0.50	0.15	0.38	0.50	0.16	0.14	0.14	0.13	0.14
pdh-5-3	0.32	0.49	0.32	0.28	0.49	0.31	0.06	0.05	0.06	0.05
polska-4-1	0.50	0.45	0.45	0.49	0.34	0.34	0.33	0.34	0.34	0.35
polska-5-1	0.44	0.42	0.42	0.41	0.16	0.16	0.15	0.16	0.15	0.16
polska-5-2	0.36	0.15	0.39	0.14	0.15	0.40	0.15	0.15	0.15	0.15

Table A.36: Time consumation (s) for node-disjointness on SNDlib instances.

	MSVND with											
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
dfn-gwin-3-1	10748.67	985.45	10733.20	650.28	10527.47	1078.69	10733.07	780.50	10779.60	867.23	10719.07	1022.25
dfn-gwin-3-2	35120.00	0.00	35120.00	0.00	35120.00	0.00	22916.00	754.91	22948.13	841.04	22795.33	1098.85
dfn-gwin-4-1	9324.40	580.01	9149.87	516.11	9028.53	627.12	9267.73	593.88	9205.47	532.78	9056.67	592.71
dfn-gwin-4-2	32532.00	0.00	32532.00	0.00	32532.00	0.00	18965.87	863.48	19124.27	714.96	18839.73	724.34
dfn-gwin-5-1	8451.07	497.11	8308.53	315.58	8385.87	341.77	8530.40	477.45	8404.27	328.26	8310.27	284.00
dfn-gwin-5-2	32532.00	0.00	32532.00	0.00	32532.00	0.00	17338.27	486.99	17565.60	493.14	17397.20	617.25
di-yuan-3-1	298446.67	18314.19	294360.00	18906.19	291596.67	20456.86	294950.00	16394.99	295413.33	11901.51	300570.00	19439.37
di-yuan-3-2	1200500.00	0.00	1200500.00	0.00	1200500.00	0.00	733363.33	29356.30	741590.00	24053.65	738206.67	26095.57
di-yuan-3-3	1553000.00	0.00	1553000.00	0.00	1553000.00	0.00	1074016.67	35345.12	1066076.67	27593.47	1072493.33	38953.56
di-yuan-4-1	277916.67	11426.41	273263.33	12067.93	277373.33	11050.66	277336.67	10670.79	275843.33	9846.40	276403.33	12345.81
di-yuan-4-2	1100700.00	0.00	1100700.00	0.00	1100700.00	0.00	590313.33	33013.12	588073.33	28170.21	591640.00	27002.17
di-yuan-4-3	1461800.00	0.00	1461800.00	0.00	1461800.00	0.00	912066.67	41886.52	905486.67	25504.19	907546.67	27323.84
di-yuan-5-1	257623.33	10314.89	261490.00	11165.78	260266.67	11479.14	258836.67	12458.86	261926.67	11535.73	265763.33	11157.08
di-yuan-5-2	929800.00	0.00	929800.00	0.00	929800.00	0.00	555800.00	18737.26	554570.00	20024.44	556213.33	14883.68
di-yuan-5-3	1386800.00	0.00	1386800.00	0.00	1386800.00	0.00	873363.33	35296.32	869400.00	26130.07	861590.00	25652.97
nobel-us-3-1	165174.67	406.11	165485.00	1470.02	165284.33	1226.85	165862.33	1613.77	165523.33	1367.11	165509.00	1312.68
nobel-us-4-1	146077.33	6531.84	150113.00	6303.42	149115.33	7887.18	147271.33	7407.67	147629.33	6841.50	147844.67	7265.36
nobel-us-5-1	115286.00	2965.64	115028.67	2743.18	115172.00	3373.07	114679.67	2757.93	115477.00	3074.40	114985.33	2582.21
nobel-us-5-2	189130.00	0.00	189130.00	0.00	189130.00	0.00	173233.67	1129.90	173272.00	1258.72	173482.00	1277.93
pdh-3-1	996233.93	44243.11	1007192.53	51733.15	1012943.90	54695.20	1001578.43	44429.84	991159.93	43772.83	1009968.80	43878.05
pdh-3-2	2110983.00	0.00	2110983.00	0.00	2110983.00	0.00	1989363.33	62337.14	1984166.83	46385.83	2008665.63	56525.28
pdh-3-3	2984244.00	0.00	2984244.00	0.00	2984244.00	0.00	2753602.50	78087.78	2741996.00	65086.19	2763652.93	72380.88
pdh-4-1	966336.10	32842.72	966494.83	32846.19	965546.77	20298.99	972279.53	35261.07	965468.27	22873.10	959641.63	33007.12
pdh-4-2	2068053.00	0.00	2068053.00	0.00	2068053.00	0.00	1835901.27	62751.95	1858877.33	65951.27	1868556.33	65621.43
pdh-4-3	2719333.00	0.00	2719333.00	0.00	2719333.00	0.00	2568698.73	86639.80	2569192.13	77203.47	2555198.43	64356.75
pdh-5-1	954446.30	17665.14	953549.97	16565.31	949012.17	16403.33	947588.33	12887.44	951219.23	15165.71	956183.40	17811.45
pdh-5-2	2159831.00	0.00	2159831.00	0.00	2159831.00	0.00	1776350.67	57610.94	1779393.47	56471.07	1777205.90	51254.61
pdh-5-3	2702903.00	0.00	2702903.00	0.00	2702903.00	0.00	2468576.53	58491.65	2483138.47	82564.42	2458165.43	71824.85
polska-4-1	2825.40	76.13	2824.67	84.79	2806.67	93.43	2856.77	93.03	2804.30	89.66	2822.10	81.76
polska-5-1	2380.70	101.27	2354.93	86.20	2374.90	110.56	2321.30	66.83	2340.27	87.86	2345.60	99.46
polska-5-2	4125.00	0.00	4125.00	0.00	4125.00	0.00	3926.83	132.44	3945.13	127.78	3914.20	115.31

Table A.37: Results for node-disjointness on SNDlib instances.

	MSVND with											
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
dfn-gwin-3-1	1.85	0.20	1.81	0.16	1.88	0.24	1.86	0.15	1.89	0.22	1.82	0.18
dfn-gwin-3-2	23.50	0.05	23.51	0.03	23.52	0.03	1.09	0.07	1.10	0.06	1.07	0.05
dfn-gwin-4-1	1.23	0.12	1.27	0.16	1.24	0.16	1.26	0.13	1.30	0.14	1.33	0.12
dfn-gwin-4-2	26.26	0.05	26.28	0.04	26.31	0.05	1.16	0.04	1.18	0.07	1.15	0.02
dfn-gwin-5-1	1.16	0.18	1.19	0.19	1.23	0.14	1.27	0.14	1.23	0.14	1.23	0.17
dfn-gwin-5-2	32.42	2.66	31.65	0.05	32.06	1.48	1.29	0.07	1.26	0.03	1.34	0.20
di-yuan-3-1	0.69	0.09	0.68	0.06	0.70	0.07	0.69	0.08	0.71	0.07	0.71	0.09
di-yuan-3-2	4.28	0.45	4.24	0.24	4.52	0.84	0.51	0.06	0.47	0.05	0.47	0.06
di-yuan-3-3	4.42	0.03	4.46	0.15	4.60	0.31	0.62	0.10	0.58	0.14	0.54	0.06
di-yuan-4-1	0.46	0.05	0.47	0.05	0.47	0.05	0.48	0.06	0.48	0.03	0.47	0.06
di-yuan-4-2	4.46	0.01	4.47	0.08	5.11	0.58	0.63	0.13	0.74	0.15	0.57	0.13
di-yuan-4-3	5.58	0.02	5.59	0.02	5.58	0.02	0.63	0.08	0.62	0.08	0.64	0.09
di-yuan-5-1	0.37	0.04	0.35	0.04	0.36	0.03	0.37	0.05	0.35	0.04	0.37	0.03
di-yuan-5-2	5.28	0.02	5.28	0.02	5.30	0.02	0.58	0.09	0.62	0.09	0.62	0.07
di-yuan-5-3	6.40	0.02	6.40	0.02	6.40	0.02	0.72	0.10	0.76	0.08	0.70	0.11
nobel-us-3-1	3.37	0.70	2.88	0.16	3.30	0.77	3.05	0.49	2.91	0.15	2.94	0.15
nobel-us-4-1	2.24	0.35	2.11	0.26	2.21	0.33	2.15	0.32	2.15	0.28	2.19	0.29
nobel-us-5-1	2.27	0.26	2.25	0.25	2.22	0.25	2.24	0.26	2.39	0.23	2.21	0.20
nobel-us-5-2	2.76	0.01	2.76	0.01	2.76	0.01	2.50	0.08	2.47	0.01	2.47	0.02
pdh-3-1	0.45	0.06	0.44	0.06	0.46	0.06	0.48	0.09	0.44	0.07	0.45	0.05
pdh-3-2	3.87	0.01	3.87	0.01	3.88	0.01	0.58	0.12	0.57	0.13	0.53	0.11
pdh-3-3	3.07	0.01	3.07	0.01	3.07	0.01	0.49	0.06	0.50	0.05	0.50	0.07
pdh-4-1	0.38	0.07	0.36	0.05	0.36	0.05	0.37	0.05	0.36	0.04	0.37	0.04
pdh-4-2	4.24	0.01	4.25	0.01	4.25	0.01	0.56	0.08	0.54	0.09	0.56	0.10
pdh-4-3	4.28	0.01	4.28	0.01	4.28	0.01	0.55	0.05	0.60	0.09	0.56	0.06
pdh-5-1	0.35	0.04	0.35	0.05	0.35	0.05	0.36	0.04	0.35	0.04	0.34	0.05
pdh-5-2	4.50	0.01	6.09	1.24	4.60	0.46	0.63	0.10	0.64	0.11	0.61	0.12
pdh-5-3	4.92	0.78	5.50	0.81	4.88	0.44	0.76	0.10	0.74	0.11	0.75	0.10
polska-4-1	1.65	0.17	1.74	0.24	1.71	0.19	1.68	0.22	1.68	0.21	1.70	0.15
polska-5-1	1.04	0.13	1.06	0.12	1.06	0.12	1.06	0.12	1.03	0.13	1.03	0.10
polska-5-2	1.60	0.02	1.62	0.01	1.61	0.01	1.57	0.15	1.58	0.14	1.66	0.18

Table A.38: Time consumation (s) for node-disjointness on SNDlib instances.

	GRASP											
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
dfn-gwin-3-1	12892.00	0.00	12892.00	0.00	12892.00	0.00	12892.00	0.00	12892.00	0.00	12892.00	0.00
dfn-gwin-3-2	19932.00	0.00	21151.73	1897.98	21691.20	1689.59	22765.47	1493.57	25544.27	1560.35	28129.07	2489.14
dfn-gwin-4-1	9952.00	0.00	9952.00	0.00	9952.00	0.00	9952.00	0.00	9952.00	0.00	9952.00	0.00
dfn-gwin-4-2	19284.00	0.00	18228.00	1176.50	18191.73	1149.49	19332.40	1329.82	22008.67	2440.35	23619.47	1847.89
dfn-gwin-5-1	9952.00	0.00	9952.00	0.00	9952.00	0.00	9952.00	0.00	9952.00	0.00	9952.00	0.00
dfn-gwin-5-2	16692.00	0.00	16166.40	835.18	16115.73	843.30	16976.40	1512.71	19303.73	1532.54	21122.00	1539.95
di-yuan-3-1	304100.00	0.00	304100.00	0.00	304100.00	0.00	304100.00	0.00	304100.00	0.00	304100.00	0.00
di-yuan-3-2	726596.67	22605.48	749130.00	34380.62	812743.33	49415.72	943576.67	80410.10	1041013.33	92427.44	1134680.00	108955.72
di-yuan-3-3	1005770.00	6105.80	1007066.67	38658.05	1076456.67	46259.65	1192290.00	84232.45	1269506.67	88518.34	1382300.00	103936.96
di-yuan-4-1	304100.00	0.00	304100.00	0.00	304100.00	0.00	304100.00	0.00	304100.00	0.00	304100.00	0.00
di-yuan-4-2	581100.00	0.00	553530.00	29336.80	651493.33	57221.31	792353.33	66397.67	871920.00	105896.97	985583.33	128221.92
di-yuan-4-3	783500.00	0.00	784933.33	26245.78	861473.33	49269.64	1008186.67	78841.31	1071533.33	80023.98	1218160.00	136794.00
di-yuan-5-1	304100.00	0.00	304100.00	0.00	304100.00	0.00	304100.00	0.00	304100.00	0.00	304100.00	0.00
di-yuan-5-2	494500.00	0.00	506713.33	33191.29	609376.67	42707.61	729533.33	82947.61	791880.00	102016.66	889256.67	92704.17
di-yuan-5-3	718600.00	0.00	728360.00	34032.83	798726.67	53572.55	958650.00	83557.56	1007790.00	93798.13	1137133.33	99065.17
nobel-us-3-1	169070.00	0.00	169070.00	0.00	169070.00	0.00	169070.00	0.00	169070.00	0.00	169070.00	0.00
nobel-us-4-1	169070.00	0.00	169070.00	0.00	169070.00	0.00	169070.00	0.00	169070.00	0.00	169070.00	0.00
nobel-us-5-1	169070.00	0.00	169070.00	0.00	169070.00	0.00	169070.00	0.00	169070.00	0.00	169070.00	0.00
nobel-us-5-2	169070.00	0.00	169500.00	437.35	169600.33	655.38	169629.00	897.37	173656.67	3300.64	173241.00	3068.01
pdh-3-1	1116079.00	0.00	1116079.00	0.00	1116079.00	0.00	1116079.00	0.00	1116079.00	0.00	1116079.00	0.00
pdh-3-2	1874780.00	0.00	1859078.10	38923.07	1881384.03	51708.32	1958200.87	75675.37	2039962.20	104718.20	2150720.33	105185.94
pdh-3-3	2440112.00	0.00	2418393.47	38473.72	2430076.83	65563.67	2483416.60	78285.02	2515093.97	90993.18	2697453.10	126554.47
pdh-4-1	1022676.00	0.00	1022676.00	0.00	1022676.00	0.00	1022676.00	0.00	1022676.00	0.00	1022676.00	0.00
pdh-4-2	1769088.00	0.00	1668731.20	96589.76	1691677.40	83954.11	1721640.30	58626.67	1809276.73	120326.15	1887576.63	78008.86
pdh-4-3	2112539.00	0.00	2156943.67	96992.90	2132033.30	49407.87	2167189.37	83659.84	2220374.33	106744.37	2321251.57	120174.75
pdh-5-1	1022676.00	0.00	1022676.00	0.00	1022676.00	0.00	1022676.00	0.00	1022676.00	0.00	1022676.00	0.00
pdh-5-2	1521083.00	0.00	1533392.27	42693.22	1532012.17	73272.57	1591438.47	85027.99	1607739.63	86457.12	1705974.50	108809.59
pdh-5-3	1947467.00	0.00	1954746.73	58234.02	1987865.37	98540.26	2010805.70	112816.22	2037022.17	89738.37	2164753.07	113850.66
polska-4-1	2693.00	0.00	2693.00	0.00	2693.00	0.00	2693.00	0.00	2693.00	0.00	2693.00	0.00
polska-5-1	2693.00	0.00	2693.00	0.00	2693.00	0.00	2693.00	0.00	2693.00	0.00	2693.00	0.00
polska-5-2	3761.00	0.00	3764.60	9.34	3777.20	13.45	3772.70	13.61	3774.50	13.73	3772.70	13.61

Table A.39: Results for node-disjointness on SNDlib instances.

	GRASP											
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
dfn-gwin-3-1	1.22	0.00	1.23	0.01	1.23	0.01	1.23	0.00	1.23	0.01	1.23	0.00
dfn-gwin-3-2	0.54	0.01	0.57	0.10	0.50	0.08	0.54	0.09	0.63	0.19	0.78	0.25
dfn-gwin-4-1	1.13	0.00	1.14	0.00	1.14	0.01	1.14	0.00	1.14	0.01	1.14	0.01
dfn-gwin-4-2	0.45	0.01	0.45	0.05	0.41	0.08	0.47	0.08	0.66	0.22	0.78	0.31
dfn-gwin-5-1	1.21	0.01	1.21	0.00	1.22	0.01	1.21	0.01	1.21	0.01	1.22	0.01
dfn-gwin-5-2	0.45	0.01	0.47	0.06	0.53	0.08	0.55	0.09	0.91	0.32	1.11	0.48
di-yuan-3-1	0.15	0.00	0.15	0.01	0.15	0.00	0.15	0.01	0.16	0.01	0.15	0.01
di-yuan-3-2	0.23	0.01	0.24	0.03	0.22	0.04	0.18	0.04	0.19	0.04	0.18	0.04
di-yuan-3-3	0.35	0.01	0.35	0.02	0.31	0.03	0.28	0.05	0.28	0.06	0.23	0.04
di-yuan-4-1	0.12	0.00	0.12	0.00	0.12	0.01	0.12	0.01	0.12	0.01	0.12	0.00
di-yuan-4-2	0.25	0.01	0.27	0.03	0.24	0.04	0.19	0.04	0.17	0.05	0.18	0.04
di-yuan-4-3	0.33	0.01	0.34	0.03	0.32	0.04	0.29	0.05	0.28	0.05	0.27	0.06
di-yuan-5-1	0.13	0.01	0.13	0.01	0.13	0.01	0.13	0.01	0.13	0.01	0.13	0.00
di-yuan-5-2	0.30	0.01	0.29	0.03	0.27	0.05	0.20	0.04	0.19	0.05	0.19	0.05
di-yuan-5-3	0.32	0.02	0.35	0.04	0.33	0.04	0.27	0.06	0.30	0.07	0.26	0.07
nobel-us-3-1	0.31	0.01	0.31	0.00	0.31	0.01	0.31	0.01	0.31	0.00	0.31	0.01
nobel-us-4-1	0.37	0.00	0.37	0.01	0.37	0.01	0.37	0.00	0.37	0.01	0.37	0.01
nobel-us-5-1	0.41	0.00	0.41	0.00	0.41	0.00	0.41	0.01	0.41	0.01	0.41	0.01
nobel-us-5-2	0.64	0.01	0.64	0.01	0.64	0.03	0.62	0.02	0.66	0.03	0.61	0.07
pdh-3-1	0.21	0.01	0.21	0.01	0.21	0.00	0.21	0.00	0.21	0.00	0.21	0.00
pdh-3-2	0.20	0.01	0.19	0.03	0.19	0.03	0.17	0.04	0.17	0.03	0.17	0.04
pdh-3-3	0.26	0.01	0.25	0.01	0.27	0.03	0.25	0.03	0.23	0.04	0.24	0.03
pdh-4-1	0.24	0.01	0.24	0.00	0.24	0.00	0.24	0.00	0.24	0.01	0.24	0.01
pdh-4-2	0.25	0.01	0.20	0.03	0.21	0.03	0.17	0.04	0.18	0.04	0.19	0.05
pdh-4-3	0.28	0.00	0.29	0.03	0.30	0.03	0.30	0.04	0.29	0.04	0.26	0.06
pdh-5-1	0.25	0.01	0.25	0.01	0.25	0.01	0.25	0.01	0.25	0.01	0.25	0.01
pdh-5-2	0.16	0.01	0.20	0.03	0.20	0.03	0.19	0.04	0.23	0.05	0.19	0.05
pdh-5-3	0.33	0.01	0.33	0.03	0.33	0.04	0.32	0.04	0.30	0.04	0.28	0.05
polska-4-1	0.41	0.01	0.41	0.01	0.40	0.01	0.40	0.01	0.41	0.01	0.40	0.01
polska-5-1	0.44	0.01	0.44	0.00	0.44	0.01	0.44	0.01	0.44	0.01	0.44	0.00
polska-5-2	0.44	0.01	0.44	0.01	0.44	0.01	0.43	0.01	0.42	0.02	0.40	0.04

Table A.40: Time consumation (s) for node-disjointness on SNDlib instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F	**BOT**
TC-21-5-1-3-1	153	153	153	153	136	136	136	136	136	136	**116**
TC-21-5-2-3-1	221	221	221	221	174	174	174	174	174	174	**166**
TC-21-5-3-3-1	198	198	198	198	108	108	108	108	108	108	**102**
TC-21-5-4-3-1	221	221	221	221	184	184	184	184	184	184	**160**
TC-21-5-5-3-1	201	201	201	201	171	171	171	171	171	171	**157**
TC-21-5-1-3-2	282	720	282	301	720	282	266	266	266	266	**210**
TC-21-5-2-3-2	389	812	463	462	812	463	385	385	385	385	**260**
TC-21-5-3-3-2	252	488	417	346	488	386	285	285	285	285	**188**
TC-21-5-4-3-2	397	1025	447	399	1025	419	358	358	358	358	**269**
TC-21-5-5-3-2	274	965	436	391	965	344	333	333	333	333	**262**
TC-21-5-1-3-3	413	1056	467	448	1056	433	427	427	427	427	**336**
TC-21-5-2-3-3	663	1093	737	690	1093	700	597	597	597	597	**416**
TC-21-5-3-3-3	490	602	615	509	602	614	460	460	460	460	**299**
TC-21-5-4-3-3	566	1387	616	603	1387	588	581	581	581	581	**425**
TC-21-5-5-3-3	494	1295	649	651	1295	516	552	552	552	552	**404**
TC-21-5-1-4-1	153	153	153	153	136	136	136	136	136	136	**116**
TC-21-5-2-4-1	221	221	221	221	174	174	174	174	174	174	**166**
TC-21-5-3-4-1	198	198	198	198	108	108	108	108	108	108	**102**
TC-21-5-4-4-1	221	221	221	221	184	184	184	184	184	184	**160**
TC-21-5-5-4-1	201	201	201	201	171	171	171	171	171	171	**157**
TC-21-5-1-4-2	269	819	297	301	819	283	266	266	266	266	**210**
TC-21-5-2-4-2	409	912	455	462	912	431	349	349	349	349	**260**
TC-21-5-3-4-2	276	582	408	346	582	350	244	244	244	244	**188**
TC-21-5-4-4-2	362	1199	436	399	1199	384	358	358	358	358	**269**
TC-21-5-5-4-2	389	1155	484	391	1155	419	319	319	319	319	**262**
TC-21-5-1-4-3	422	1172	464	448	1172	422	416	416	416	416	**327**
TC-21-5-2-4-3	557	1216	629	690	1216	557	560	560	560	560	**410**
TC-21-5-3-4-3	418	727	616	509	727	542	369	369	369	369	**299**
TC-21-5-4-4-3	502	1401	638	603	1401	546	565	565	565	565	**413**
TC-21-5-5-4-3	484	1337	769	651	1337	494	534	534	534	534	**400**
TC-21-5-1-5-1	153	153	153	153	136	136	136	136	136	136	**116**
TC-21-5-2-5-1	221	221	221	221	174	174	174	174	174	174	**166**
TC-21-5-3-5-1	198	198	198	198	108	108	108	108	108	108	**102**
TC-21-5-4-5-1	221	221	221	221	184	184	184	184	184	184	**160**
TC-21-5-5-5-1	201	201	201	201	171	171	171	171	171	171	**157**
TC-21-5-1-5-2	277	854	291	301	854	291	266	266	266	266	**206**
TC-21-5-2-5-2	400	960	434	462	960	400	349	349	349	349	**244**
TC-21-5-3-5-2	268	641	354	346	641	354	244	244	244	244	**182**
TC-21-5-4-5-2	362	1151	436	399	1151	362	358	358	358	358	**249**
TC-21-5-5-5-2	363	1033	448	391	1033	383	319	319	319	319	**232**
TC-21-5-1-5-3	420	1239	456	448	1239	434	416	416	416	416	**327**
TC-21-5-2-5-3	607	1369	653	690	1369	607	549	549	549	549	**410**
TC-21-5-3-5-3	444	793	598	509	793	574	369	369	369	369	**299**
TC-21-5-4-5-3	502	1457	646	603	1457	524	565	565	565	565	**413**
TC-21-5-5-5-3	566	1365	709	651	1365	586	534	534	534	534	**400**

Table A.41: Results for edge-disjointness on TC-21-5 instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TC-21-5-1-3-1	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
TC-21-5-2-3-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TC-21-5-3-3-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TC-21-5-4-3-1	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01
TC-21-5-5-3-1	0.02	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00
TC-21-5-1-3-2	0.20	0.02	0.10	0.01	0.04	0.10	0.00	0.00	0.00	0.00
TC-21-5-2-3-2	0.20	0.02	0.19	0.00	0.03	0.20	0.00	0.00	0.01	0.01
TC-21-5-3-3-2	0.30	0.04	0.23	0.00	0.04	0.19	0.01	0.01	0.01	0.00
TC-21-5-4-3-2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TC-21-5-5-3-2	0.31	0.02	0.23	0.00	0.04	0.20	0.00	0.00	0.01	0.01
TC-21-5-1-3-3	0.25	0.04	0.14	0.01	0.04	0.14	0.01	0.01	0.01	0.01
TC-21-5-2-3-3	0.35	0.03	0.28	0.00	0.04	0.25	0.01	0.01	0.00	0.01
TC-21-5-3-3-3	0.38	0.04	0.31	0.00	0.04	0.28	0.01	0.01	0.01	0.01
TC-21-5-4-3-3	0.42	0.04	0.20	0.01	0.05	0.17	0.01	0.00	0.01	0.01
TC-21-5-5-3-3	0.35	0.03	0.30	0.01	0.05	0.20	0.00	0.01	0.00	0.01
TC-21-5-1-4-1	0.47	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TC-21-5-2-4-1	0.50	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01
TC-21-5-3-4-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TC-21-5-4-4-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TC-21-5-5-4-1	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TC-21-5-1-4-2	0.77	0.49	0.59	0.00	0.54	0.55	0.00	0.00	0.01	0.01
TC-21-5-2-4-2	0.63	0.52	0.70	0.00	0.53	0.70	0.00	0.00	0.00	0.01
TC-21-5-3-4-2	0.76	0.52	0.67	0.01	0.51	0.68	0.01	0.00	0.01	0.01
TC-21-5-4-4-2	0.85	0.55	0.64	0.01	0.47	0.61	0.01	0.01	0.01	0.01
TC-21-5-5-4-2	0.78	0.51	0.69	0.01	0.50	0.65	0.01	0.00	0.01	0.01
TC-21-5-1-4-3	0.86	0.55	0.65	0.01	0.55	0.65	0.01	0.01	0.01	0.01
TC-21-5-2-4-3	0.73	0.55	0.75	0.02	0.56	0.80	0.02	0.02	0.01	0.01
TC-21-5-3-4-3	0.99	0.56	0.84	0.01	0.53	0.84	0.01	0.01	0.01	0.00
TC-21-5-4-4-3	1.13	0.53	0.69	0.01	0.56	0.73	0.01	0.01	0.02	0.02
TC-21-5-5-4-3	1.02	0.56	0.89	0.02	0.57	0.81	0.01	0.01	0.01	0.01
TC-21-5-1-5-1	0.37	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
TC-21-5-2-5-1	8.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
TC-21-5-3-5-1	8.27	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01
TC-21-5-4-5-1	8.03	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01
TC-21-5-5-5-1	8.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
TC-21-5-1-5-2	9.09	8.74	8.71	0.01	8.86	8.80	0.01	0.00	0.01	0.00
TC-21-5-2-5-2	8.96	8.53	8.97	0.01	8.77	8.65	0.02	0.01	0.01	0.00
TC-21-5-3-5-2	9.07	8.75	9.02	0.00	8.87	9.11	0.01	0.01	0.00	0.01
TC-21-5-4-5-2	9.14	8.90	8.84	0.00	8.81	9.16	0.01	0.00	0.01	0.01
TC-21-5-5-5-2	9.08	8.70	9.08	0.01	8.76	8.99	0.01	0.01	0.01	0.01
TC-21-5-1-5-3	10.06	9.33	9.51	0.01	9.50	9.64	0.01	0.01	0.01	0.01
TC-21-5-2-5-3	9.68	9.31	9.49	0.01	9.44	9.50	0.01	0.02	0.01	0.01
TC-21-5-3-5-3	9.59	9.05	9.68	0.01	9.20	9.60	0.01	0.01	0.01	0.01
TC-21-5-4-5-3	10.81	9.30	9.51	0.02	9.38	9.56	0.01	0.01	0.00	0.01
TC-21-5-5-5-3	10.06	9.40	10.03	0.01	9.36	9.79	0.00	0.00	0.01	0.01

Table A.42: Time consumation (s) for edge-disjointness on TC-21-5 instances.

	VND with										
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F	**BOT**
TC-21-5-1-3-1	116	116	116	116	116	116	116	116	116	116	**116**
TC-21-5-2-3-1	174	174	174	174	174	174	174	174	174	174	**166**
TC-21-5-3-3-1	114	114	114	114	102	102	102	102	102	102	**102**
TC-21-5-4-3-1	168	168	168	168	168	168	168	168	168	168	**160**
TC-21-5-5-3-1	157	157	157	157	162	162	162	162	162	162	**157**
TC-21-5-1-3-2	250	235	250	235	235	250	235	235	235	235	**210**
TC-21-5-2-3-2	329	325	329	286	325	329	260	260	260	260	**260**
TC-21-5-3-3-2	196	231	196	188	231	196	188	188	188	188	**188**
TC-21-5-4-3-2	336	269	336	304	269	336	304	304	304	304	**269**
TC-21-5-5-3-2	266	262	306	262	262	266	262	262	262	262	**262**
TC-21-5-1-3-3	374	344	391	376	344	374	376	376	376	376	**336**
TC-21-5-2-3-3	513	436	477	472	436	513	472	472	472	472	**416**
TC-21-5-3-3-3	336	422	336	336	422	417	336	336	336	336	**299**
TC-21-5-4-3-3	449	437	449	473	437	449	473	473	473	473	**425**
TC-21-5-5-3-3	463	439	514	443	439	461	443	443	443	443	**404**
TC-21-5-1-4-1	116	116	116	116	116	116	116	116	116	116	**116**
TC-21-5-2-4-1	174	174	174	174	174	174	174	174	174	174	**166**
TC-21-5-3-4-1	114	114	114	114	102	102	102	102	102	102	**102**
TC-21-5-4-4-1	168	168	168	168	168	168	168	168	168	168	**160**
TC-21-5-5-4-1	157	157	157	157	162	162	162	162	162	162	**157**
TC-21-5-1-4-2	249	245	263	235	245	263	235	235	235	235	**210**
TC-21-5-2-4-2	349	293	369	333	293	369	349	349	349	349	**260**
TC-21-5-3-4-2	230	197	204	188	197	204	204	204	204	204	**188**
TC-21-5-4-4-2	332	325	356	332	325	332	304	304	304	304	**269**
TC-21-5-5-4-2	366	294	347	279	294	378	279	279	279	279	**262**
TC-21-5-1-4-3	361	344	361	367	344	361	365	365	365	365	**327**
TC-21-5-2-4-3	500	560	526	472	560	500	475	475	475	475	**410**
TC-21-5-3-4-3	390	384	414	336	384	426	344	344	344	344	**299**
TC-21-5-4-4-3	495	481	521	473	481	475	495	495	495	495	**413**
TC-21-5-5-4-3	461	671	473	478	671	473	478	478	478	478	**400**
TC-21-5-1-5-1	116	116	116	116	116	116	116	116	116	116	**116**
TC-21-5-2-5-1	174	174	174	174	174	174	174	174	174	174	**166**
TC-21-5-3-5-1	114	114	114	114	102	102	102	102	102	102	**102**
TC-21-5-4-5-1	168	168	168	168	168	168	168	168	168	168	**160**
TC-21-5-5-5-1	157	157	157	157	162	162	162	162	162	162	**157**
TC-21-5-1-5-2	249	245	263	235	245	263	235	235	235	235	**206**
TC-21-5-2-5-2	356	368	368	284	368	356	331	331	331	331	**244**
TC-21-5-3-5-2	204	228	204	188	228	204	204	204	204	204	**182**
TC-21-5-4-5-2	332	297	334	332	297	332	304	304	304	304	**249**
TC-21-5-5-5-2	311	280	355	279	280	311	279	279	279	279	**232**
TC-21-5-1-5-3	358	344	361	367	344	361	365	365	365	365	**327**
TC-21-5-2-5-3	514	520	514	472	520	514	482	482	482	482	**410**
TC-21-5-3-5-3	410	384	411	336	384	388	344	344	344	344	**299**
TC-21-5-4-5-3	495	455	509	473	455	517	495	495	495	495	**413**
TC-21-5-5-5-3	535	584	451	478	584	535	478	478	478	478	**400**

Table A.43: Results for edge-disjointness on TC-21-5 instances.

	VND with									
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TC-21-5-1-3-1	0.05	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02
TC-21-5-2-3-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TC-21-5-3-3-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TC-21-5-4-3-1	0.06	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.02
TC-21-5-5-3-1	0.06	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
TC-21-5-1-3-2	0.26	0.13	0.18	0.05	0.12	0.18	0.03	0.03	0.03	0.03
TC-21-5-2-3-2	0.32	0.13	0.31	0.10	0.13	0.33	0.06	0.05	0.06	0.05
TC-21-5-3-3-2	0.40	0.12	0.37	0.06	0.13	0.31	0.10	0.10	0.10	0.09
TC-21-5-4-3-2	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00
TC-21-5-5-3-2	0.38	0.13	0.32	0.08	0.13	0.29	0.06	0.06	0.06	0.06
TC-21-5-1-3-3	0.36	0.14	0.22	0.08	0.15	0.26	0.05	0.05	0.06	0.05
TC-21-5-2-3-3	0.55	0.21	0.47	0.15	0.21	0.43	0.08	0.08	0.07	0.08
TC-21-5-3-3-3	0.57	0.10	0.52	0.07	0.11	0.50	0.08	0.09	0.09	0.09
TC-21-5-4-3-3	0.52	0.15	0.34	0.13	0.15	0.33	0.11	0.10	0.11	0.11
TC-21-5-5-3-3	0.41	0.15	0.39	0.13	0.13	0.27	0.08	0.09	0.09	0.08
TC-21-5-1-4-1	0.51	0.04	0.05	0.03	0.02	0.02	0.02	0.02	0.02	0.01
TC-21-5-2-4-1	0.54	0.02	0.03	0.03	0.01	0.02	0.02	0.02	0.02	0.02
TC-21-5-3-4-1	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TC-21-5-4-4-1	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TC-21-5-5-4-1	0.50	0.03	0.04	0.03	0.02	0.03	0.02	0.03	0.02	0.03
TC-21-5-1-4-2	0.72	0.58	0.61	0.06	0.60	0.67	0.04	0.03	0.04	0.04
TC-21-5-2-4-2	0.80	0.65	0.74	0.11	0.69	0.78	0.03	0.03	0.03	0.03
TC-21-5-3-4-2	0.87	0.61	0.85	0.08	0.61	0.77	0.07	0.06	0.06	0.06
TC-21-5-4-4-2	0.88	0.65	0.73	0.08	0.58	0.73	0.10	0.09	0.09	0.09
TC-21-5-5-4-2	0.88	0.67	0.79	0.11	0.67	0.78	0.09	0.09	0.09	0.08
TC-21-5-1-4-3	1.05	0.74	0.82	0.11	0.77	0.82	0.06	0.06	0.06	0.06
TC-21-5-2-4-3	0.93	0.78	0.80	0.15	0.74	0.89	0.13	0.12	0.12	0.12
TC-21-5-3-4-3	1.10	0.61	1.02	0.09	0.67	0.92	0.07	0.07	0.08	0.07
TC-21-5-4-4-3	1.23	0.78	0.87	0.16	0.83	0.85	0.14	0.13	0.13	0.13
TC-21-5-5-4-3	1.11	0.66	1.01	0.12	0.66	0.89	0.08	0.08	0.07	0.08
TC-21-5-1-5-1	1.04	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00
TC-21-5-2-5-1	8.17	0.04	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.03
TC-21-5-3-5-1	8.32	0.04	0.04	0.04	0.03	0.02	0.03	0.03	0.03	0.03
TC-21-5-4-5-1	8.26	0.04	0.04	0.04	0.03	0.03	0.04	0.03	0.03	0.03
TC-21-5-5-5-1	8.02	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03
TC-21-5-1-5-2	9.08	9.03	8.94	0.07	9.00	8.84	0.04	0.05	0.04	0.05
TC-21-5-2-5-2	9.01	8.74	9.10	0.13	8.84	8.79	0.07	0.07	0.07	0.08
TC-21-5-3-5-2	9.11	9.00	9.00	0.10	8.99	9.06	0.07	0.07	0.07	0.07
TC-21-5-4-5-2	9.41	8.89	9.13	0.09	8.98	9.04	0.09	0.10	0.10	0.11
TC-21-5-5-5-2	9.08	8.74	9.16	0.13	9.03	9.01	0.10	0.11	0.10	0.10
TC-21-5-1-5-3	10.11	9.74	9.66	0.13	9.72	9.55	0.07	0.07	0.06	0.07
TC-21-5-2-5-3	9.91	9.65	9.76	0.17	9.53	9.91	0.17	0.18	0.18	0.17
TC-21-5-3-5-3	9.80	9.44	9.92	0.11	9.56	9.96	0.09	0.08	0.09	0.08
TC-21-5-4-5-3	11.00	9.56	9.65	0.19	9.81	9.71	0.16	0.16	0.15	0.15
TC-21-5-5-5-3	10.09	9.57	9.87	0.15	9.63	10.11	0.09	0.08	0.09	0.09

Table A.44: Time consumation (s) for edge-disjointness on TC-21-5 instances.

	MSVND with												
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F		
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	**BOT**
TC-21-5-1-3-1	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	**116**
TC-21-5-2-3-1	166.00	0.00	166.00	0.00	166.00	0.00	166.00	0.00	166.00	0.00	166.00	0.00	**166**
TC-21-5-3-3-1	102.40	2.19	102.00	0.00	102.40	2.19	102.80	3.04	102.40	2.19	102.00	0.00	**102**
TC-21-5-4-3-1	163.33	1.27	163.83	1.90	164.00	2.03	163.83	1.90	164.57	5.10	164.00	2.03	**160**
TC-21-5-5-3-1	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	**157**
TC-21-5-1-3-2	235.00	0.00	235.00	0.00	235.00	0.00	235.00	0.00	235.00	0.00	235.00	0.00	**210**
TC-21-5-2-3-2	325.00	0.00	325.00	0.00	325.00	0.00	260.00	0.00	260.00	0.00	260.00	0.00	**260**
TC-21-5-3-3-2	231.00	0.00	231.00	0.00	231.00	0.00	188.00	0.00	188.27	1.46	188.00	0.00	**188**
TC-21-5-4-3-2	269.00	0.00	269.00	0.00	269.00	0.00	269.73	4.02	269.00	0.00	269.00	0.00	**269**
TC-21-5-5-3-2	262.00	0.00	262.00	0.00	262.00	0.00	262.00	0.00	262.00	0.00	262.00	0.00	**262**
TC-21-5-1-3-3	344.00	0.00	344.00	0.00	344.00	0.00	347.00	8.42	346.27	8.34	348.30	9.80	**336**
TC-21-5-2-3-3	436.00	0.00	436.00	0.00	436.00	0.00	466.00	9.65	470.57	11.95	465.97	11.42	**416**
TC-21-5-3-3-3	422.00	0.00	422.00	0.00	422.00	0.00	336.00	0.00	336.00	0.00	336.00	0.00	**299**
TC-21-5-4-3-3	437.00	0.00	437.00	0.00	437.00	0.00	438.20	6.57	437.33	1.83	437.00	0.00	**425**
TC-21-5-5-3-3	439.00	0.00	439.00	0.00	439.00	0.00	439.13	0.73	439.00	0.00	439.13	0.73	**404**
TC-21-5-1-4-1	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	**116**
TC-21-5-2-4-1	166.00	0.00	166.00	0.00	166.00	0.00	166.00	0.00	166.00	0.00	166.00	0.00	**166**
TC-21-5-3-4-1	102.00	0.00	102.40	2.19	102.00	0.00	102.00	0.00	102.00	0.00	102.00	0.00	**102**
TC-21-5-4-4-1	164.17	2.15	163.67	1.73	164.67	2.40	164.00	2.03	163.83	1.90	163.83	1.90	**160**
TC-21-5-5-4-1	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	**157**
TC-21-5-1-4-2	245.00	0.00	245.00	0.00	245.00	0.00	235.00	0.00	235.43	2.37	235.00	0.00	**210**
TC-21-5-2-4-2	293.00	0.00	293.00	0.00	293.00	0.00	293.53	0.90	296.60	9.64	295.50	8.63	**260**
TC-21-5-3-4-2	197.00	0.00	197.00	0.00	197.00	0.00	188.80	2.44	189.33	3.03	188.80	2.44	**188**
TC-21-5-4-4-2	325.00	0.00	325.00	0.00	325.00	0.00	274.13	7.78	272.73	7.29	271.80	5.70	**269**
TC-21-5-5-4-2	294.00	0.00	294.00	0.00	294.00	0.00	272.50	6.61	272.50	6.61	272.50	6.61	**262**
TC-21-5-1-4-3	344.00	0.00	344.00	0.00	344.00	0.00	347.33	5.83	349.87	8.36	347.10	6.70	**327**
TC-21-5-2-4-3	560.00	0.00	560.00	0.00	560.00	0.00	463.17	7.66	459.40	8.06	460.73	8.00	**410**
TC-21-5-3-4-3	384.00	0.00	384.00	0.00	384.00	0.00	337.00	0.00	337.47	1.78	337.00	0.00	**299**
TC-21-5-4-4-3	481.00	0.00	481.00	0.00	481.00	0.00	459.53	5.76	459.03	5.28	459.50	5.69	**413**
TC-21-5-5-4-3	671.00	0.00	671.00	0.00	671.00	0.00	441.47	8.23	437.40	5.52	441.90	8.61	**400**
TC-21-5-1-5-1	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	**116**
TC-21-5-2-5-1	166.00	0.00	166.00	0.00	166.00	0.00	166.00	0.00	166.00	0.00	166.00	0.00	**166**
TC-21-5-3-5-1	102.40	2.19	102.80	3.04	102.00	0.00	102.80	3.04	102.40	2.19	102.80	3.04	**102**
TC-21-5-4-5-1	164.80	3.21	163.83	1.90	163.67	1.73	163.33	1.27	163.83	1.90	163.83	1.90	**160**
TC-21-5-5-5-1	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	**157**
TC-21-5-1-5-2	245.00	0.00	245.00	0.00	245.00	0.00	235.00	0.00	235.00	0.00	235.00	0.00	**206**
TC-21-5-2-5-2	368.00	0.00	368.00	0.00	368.00	0.00	286.57	4.73	286.20	4.48	285.10	3.36	**244**
TC-21-5-3-5-2	228.00	0.00	228.00	0.00	228.00	0.00	188.80	2.44	189.60	3.25	189.07	2.77	**182**
TC-21-5-4-5-2	297.00	0.00	297.00	0.00	297.00	0.00	286.73	6.30	286.03	6.28	286.97	7.73	**249**
TC-21-5-5-5-2	280.00	0.00	280.00	0.00	280.00	0.00	274.63	11.76	273.80	6.48	274.00	9.54	**232**
TC-21-5-1-5-3	344.00	0.00	344.00	0.00	344.00	0.00	349.30	7.88	351.23	8.54	347.57	6.89	**327**
TC-21-5-2-5-3	520.00	0.00	520.00	0.00	520.00	0.00	470.23	3.85	471.07	2.42	468.73	3.55	**410**
TC-21-5-3-5-3	384.00	0.00	384.00	0.00	384.00	0.00	337.00	0.00	337.47	1.78	337.00	0.00	**299**
TC-21-5-4-5-3	455.00	0.00	455.00	0.00	455.00	0.00	458.00	3.81	460.07	6.24	459.00	5.19	**413**
TC-21-5-5-5-3	584.00	0.00	584.00	0.00	584.00	0.00	442.03	8.63	439.70	8.45	440.80	8.17	**400**

Table A.45: Results for edge-disjointness on TC-21-5 instances.

	MSVND with											
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TC-21-5-1-3-1	0.23	0.02	0.23	0.02	0.23	0.02	0.23	0.02	0.23	0.02	0.24	0.02
TC-21-5-2-3-1	0.01	0.01	0.03	0.01	0.04	0.01	0.05	0.01	0.07	0.01	0.08	0.01
TC-21-5-3-3-1	0.01	0.00	0.02	0.00	0.03	0.01	0.03	0.00	0.04	0.01	0.05	0.01
TC-21-5-4-3-1	0.19	0.01	0.19	0.01	0.18	0.01	0.18	0.01	0.18	0.01	0.18	0.01
TC-21-5-5-3-1	0.21	0.02	0.21	0.01	0.21	0.02	0.21	0.02	0.21	0.02	0.21	0.02
TC-21-5-1-3-2	1.11	0.02	1.12	0.02	1.12	0.02	0.45	0.05	0.44	0.05	0.45	0.05
TC-21-5-2-3-2	1.20	0.02	1.20	0.02	1.19	0.02	0.70	0.04	0.69	0.04	0.70	0.04
TC-21-5-3-3-2	1.09	0.01	1.09	0.01	1.08	0.02	0.54	0.05	0.52	0.06	0.54	0.05
TC-21-5-4-3-2	0.20	0.09	0.46	0.06	0.63	0.04	0.41	0.02	0.44	0.02	0.47	0.02
TC-21-5-5-3-2	1.10	0.02	1.10	0.01	1.16	0.18	0.60	0.03	0.61	0.03	0.60	0.03
TC-21-5-1-3-3	1.29	0.02	1.28	0.01	1.27	0.02	0.69	0.07	0.68	0.07	0.69	0.08
TC-21-5-2-3-3	1.93	0.02	1.92	0.02	1.93	0.02	0.68	0.05	0.68	0.04	0.68	0.04
TC-21-5-3-3-3	0.92	0.02	0.92	0.02	0.92	0.02	0.78	0.05	0.77	0.05	0.79	0.06
TC-21-5-4-3-3	1.41	0.02	1.41	0.01	1.41	0.01	0.92	0.05	0.91	0.04	0.90	0.05
TC-21-5-5-3-3	1.29	0.02	1.28	0.02	1.29	0.02	0.75	0.05	0.77	0.05	0.88	0.20
TC-21-5-1-4-1	0.26	0.02	0.27	0.02	0.28	0.02	0.27	0.02	0.26	0.02	0.26	0.02
TC-21-5-2-4-1	0.26	0.03	0.24	0.03	0.25	0.02	0.25	0.02	0.24	0.02	0.25	0.02
TC-21-5-3-4-1	0.01	0.01	0.03	0.01	0.05	0.01	0.06	0.01	0.07	0.01	0.08	0.01
TC-21-5-4-4-1	0.01	0.01	0.03	0.01	0.04	0.01	0.06	0.01	0.07	0.01	0.08	0.01
TC-21-5-5-4-1	0.24	0.02	0.24	0.02	0.25	0.02	0.24	0.02	0.24	0.02	0.24	0.02
TC-21-5-1-4-2	5.64	0.07	5.65	0.06	5.67	0.07	0.35	0.03	0.34	0.03	0.34	0.02
TC-21-5-2-4-2	6.16	0.06	6.17	0.09	6.18	0.08	0.73	0.08	0.72	0.06	0.75	0.07
TC-21-5-3-4-2	5.50	0.07	5.51	0.08	5.51	0.07	0.50	0.04	0.50	0.05	0.52	0.07
TC-21-5-4-4-2	5.76	0.08	5.76	0.08	5.74	0.06	0.63	0.09	0.64	0.07	0.65	0.07
TC-21-5-5-4-2	6.02	0.07	6.01	0.07	6.02	0.07	0.54	0.08	0.53	0.07	0.55	0.09
TC-21-5-1-4-3	6.65	0.08	6.61	0.08	6.64	0.07	0.71	0.06	0.70	0.06	0.69	0.07
TC-21-5-2-4-3	6.73	0.08	6.73	0.08	6.73	0.06	1.13	0.09	1.12	0.09	1.15	0.08
TC-21-5-3-4-3	5.64	0.07	5.62	0.07	5.63	0.07	0.76	0.09	0.76	0.10	0.76	0.10
TC-21-5-4-4-3	7.26	0.06	7.28	0.10	7.27	0.06	1.09	0.05	1.09	0.05	1.12	0.06
TC-21-5-5-4-3	6.07	0.06	6.07	0.07	6.10	0.08	0.85	0.07	0.84	0.07	0.83	0.07
TC-21-5-1-5-1	0.06	0.01	0.07	0.01	0.09	0.01	0.11	0.01	0.12	0.01	0.14	0.01
TC-21-5-2-5-1	0.27	0.03	0.28	0.03	0.29	0.03	0.28	0.02	0.29	0.03	0.28	0.02
TC-21-5-3-5-1	0.26	0.01	0.26	0.02	0.26	0.01	0.26	0.02	0.26	0.02	0.25	0.02
TC-21-5-4-5-1	0.25	0.02	0.24	0.01	0.25	0.02	0.25	0.02	0.25	0.02	0.24	0.02
TC-21-5-5-5-1	0.28	0.03	0.28	0.02	0.28	0.03	0.28	0.02	0.29	0.03	0.27	0.02
TC-21-5-1-5-2	79.59	0.30	79.79	0.29	79.81	0.36	0.40	0.03	0.39	0.02	0.40	0.04
TC-21-5-2-5-2	78.91	0.45	82.81	9.02	90.97	11.61	0.92	0.14	0.89	0.06	0.89	0.05
TC-21-5-3-5-2	79.77	0.37	79.74	0.35	79.81	0.44	0.64	0.08	0.64	0.07	0.64	0.08
TC-21-5-4-5-2	80.46	0.90	87.42	13.67	80.18	0.36	0.73	0.08	0.71	0.08	0.71	0.10
TC-21-5-5-5-2	80.28	0.31	80.21	0.34	80.27	0.31	0.82	0.05	0.81	0.04	0.82	0.04
TC-21-5-1-5-3	85.83	0.32	86.01	0.28	85.93	0.29	0.87	0.09	0.84	0.07	0.88	0.09
TC-21-5-2-5-3	85.65	0.41	85.75	0.88	85.61	0.30	1.40	0.13	1.42	0.14	1.36	0.18
TC-21-5-3-5-3	84.47	1.08	116.20	20.32	97.49	16.99	0.95	0.13	0.91	0.11	0.94	0.12
TC-21-5-4-5-3	86.41	0.28	86.55	0.40	86.54	0.36	1.25	0.06	1.27	0.06	1.28	0.06
TC-21-5-5-5-3	86.88	0.34	86.95	0.25	86.76	0.29	1.08	0.09	1.05	0.06	1.04	0.07

Table A.46: Time consumation (s) for edge-disjointness on TC-21-5 instances.

	GRASP												
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$		
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	**BOT**
TC-21-5-1-3-1	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	**116**
TC-21-5-2-3-1	174.00	0.00	174.00	0.00	174.00	0.00	174.00	0.00	174.00	0.00	174.00	0.00	**166**
TC-21-5-3-3-1	114.00	0.00	114.00	0.00	114.00	0.00	114.00	0.00	114.00	0.00	114.00	0.00	**102**
TC-21-5-4-3-1	168.00	0.00	168.00	0.00	168.00	0.00	168.00	0.00	168.00	0.00	168.00	0.00	**160**
TC-21-5-5-3-1	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	**157**
TC-21-5-1-3-2	254.87	9.93	245.40	17.23	269.63	30.33	264.83	34.23	294.50	61.54	282.30	55.32	**210**
TC-21-5-2-3-2	329.00	0.00	338.90	13.30	335.90	29.50	356.87	50.18	343.63	45.94	363.97	54.41	**260**
TC-21-5-3-3-2	196.00	0.00	210.87	24.70	228.57	36.06	251.20	47.25	259.90	75.27	253.60	49.39	**188**
TC-21-5-4-3-2	336.00	0.00	324.40	20.06	314.60	29.80	335.77	44.72	364.60	60.65	350.33	58.05	**269**
TC-21-5-5-3-2	276.67	15.34	288.63	33.11	281.67	29.68	344.73	32.95	325.60	53.78	338.73	60.80	**262**
TC-21-5-1-3-3	373.80	6.59	374.37	17.33	394.63	31.43	403.23	47.23	406.43	42.27	426.30	64.31	**336**
TC-21-5-2-3-3	513.00	0.00	513.80	30.02	497.40	25.03	521.33	43.16	540.20	48.31	543.53	60.48	**416**
TC-21-5-3-3-3	389.90	35.89	403.23	29.21	398.43	43.91	389.20	53.31	403.73	47.85	416.73	63.68	**299**
TC-21-5-4-3-3	455.80	13.83	461.37	22.50	486.33	40.32	511.63	52.45	529.23	77.01	502.93	45.85	**425**
TC-21-5-5-3-3	463.00	0.00	478.57	23.74	466.60	21.53	499.80	44.42	517.17	67.90	514.50	44.81	**404**
TC-21-5-1-4-1	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	**116**
TC-21-5-2-4-1	174.00	0.00	174.00	0.00	174.00	0.00	174.00	0.00	174.00	0.00	174.00	0.00	**166**
TC-21-5-3-4-1	114.00	0.00	114.00	0.00	114.00	0.00	114.00	0.00	114.00	0.00	114.00	0.00	**102**
TC-21-5-4-4-1	168.00	0.00	168.00	0.00	168.00	0.00	168.00	0.00	168.00	0.00	168.00	0.00	**160**
TC-21-5-5-4-1	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	**157**
TC-21-5-1-4-2	249.00	0.00	252.73	25.31	267.37	29.75	287.03	50.85	292.47	50.58	300.40	70.10	**210**
TC-21-5-2-4-2	346.57	6.55	328.33	27.03	333.27	39.08	335.20	41.58	375.97	83.82	376.93	66.78	**260**
TC-21-5-3-4-2	230.00	0.00	234.20	33.26	232.97	35.89	261.47	79.04	273.53	63.44	275.47	61.85	**188**
TC-21-5-4-4-2	333.13	1.01	318.03	19.02	318.57	23.31	366.97	57.58	367.00	67.67	378.27	66.13	**269**
TC-21-5-5-4-2	318.43	44.21	301.90	40.16	307.40	29.68	333.90	49.45	360.13	56.11	345.77	57.23	**262**
TC-21-5-1-4-3	365.67	8.60	382.50	21.13	395.20	38.61	413.83	68.70	441.03	80.69	445.53	72.08	**327**
TC-21-5-2-4-3	503.77	16.54	489.73	34.60	491.80	52.28	543.47	61.39	553.00	60.57	565.13	81.95	**410**
TC-21-5-3-4-3	388.70	8.81	404.50	24.13	396.57	60.36	410.30	73.69	430.77	94.73	424.67	87.24	**299**
TC-21-5-4-4-3	499.00	5.75	495.13	29.69	524.23	61.84	547.83	61.19	545.07	69.99	579.03	96.62	**413**
TC-21-5-5-4-3	448.67	13.40	480.87	31.39	488.83	35.92	519.17	63.77	531.73	59.51	545.80	85.13	**400**
TC-21-5-1-5-1	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	116.00	0.00	**116**
TC-21-5-2-5-1	174.00	0.00	174.00	0.00	174.00	0.00	174.00	0.00	174.00	0.00	174.00	0.00	**166**
TC-21-5-3-5-1	114.00	0.00	114.00	0.00	114.00	0.00	114.00	0.00	114.00	0.00	114.00	0.00	**102**
TC-21-5-4-5-1	168.00	0.00	168.00	0.00	168.00	0.00	168.00	0.00	168.00	0.00	168.00	0.00	**160**
TC-21-5-5-5-1	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	157.00	0.00	**157**
TC-21-5-1-5-2	254.00	8.35	249.97	21.85	267.10	47.03	285.33	63.97	305.10	80.95	285.80	53.42	**206**
TC-21-5-2-5-2	337.07	11.35	330.60	31.22	330.30	40.83	346.13	54.04	360.00	55.05	366.47	70.28	**244**
TC-21-5-3-5-2	218.73	17.14	231.57	27.54	244.27	51.41	251.73	56.96	267.00	76.15	263.43	76.22	**182**
TC-21-5-4-5-2	322.40	12.97	310.10	17.68	323.57	35.48	347.57	65.21	354.70	44.50	387.93	98.42	**249**
TC-21-5-5-5-2	301.73	15.34	307.93	28.23	305.83	31.46	332.50	43.22	354.80	71.02	365.17	88.18	**232**
TC-21-5-1-5-3	358.00	0.00	382.37	30.95	396.53	39.44	450.37	80.88	440.80	63.15	434.27	76.92	**327**
TC-21-5-2-5-3	518.43	8.17	505.37	29.26	508.23	49.73	539.80	67.11	567.00	62.85	609.90	108.95	**410**
TC-21-5-3-5-3	409.07	1.01	405.03	26.84	404.27	58.99	430.13	98.04	455.00	89.16	463.27	106.62	**299**
TC-21-5-4-5-3	499.60	2.58	497.57	36.30	518.57	57.03	529.70	70.21	558.70	88.93	591.63	76.87	**413**
TC-21-5-5-5-3	537.33	18.80	485.63	37.90	482.73	32.87	512.13	65.07	555.17	83.72	548.60	91.76	**400**

Table A.47: Results for edge-disjointness on TC-21-5 instances.

	GRASP											
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TC-21-5-1-3-1	0.06	0.01	0.06	0.01	0.06	0.01	0.06	0.01	0.06	0.01	0.06	0.01
TC-21-5-2-3-1	0.02	0.00	0.03	0.01	0.03	0.01	0.03	0.00	0.03	0.00	0.03	0.01
TC-21-5-3-3-1	0.02	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.02	0.00
TC-21-5-4-3-1	0.07	0.01	0.06	0.01	0.07	0.01	0.06	0.01	0.06	0.01	0.07	0.01
TC-21-5-5-3-1	0.06	0.01	0.06	0.01	0.06	0.01	0.06	0.01	0.06	0.01	0.06	0.01
TC-21-5-1-3-2	0.27	0.03	0.24	0.05	0.26	0.06	0.28	0.07	0.25	0.05	0.28	0.06
TC-21-5-2-3-2	0.32	0.02	0.33	0.04	0.27	0.04	0.25	0.07	0.27	0.05	0.25	0.05
TC-21-5-3-3-2	0.42	0.02	0.41	0.05	0.31	0.10	0.29	0.06	0.30	0.08	0.28	0.08
TC-21-5-4-3-2	0.23	0.01	0.25	0.06	0.25	0.08	0.22	0.06	0.22	0.06	0.22	0.07
TC-21-5-5-3-2	0.35	0.02	0.34	0.04	0.32	0.07	0.24	0.06	0.30	0.05	0.29	0.07
TC-21-5-1-3-3	0.36	0.03	0.35	0.04	0.38	0.07	0.38	0.07	0.38	0.08	0.42	0.08
TC-21-5-2-3-3	0.53	0.02	0.45	0.05	0.43	0.08	0.41	0.09	0.40	0.07	0.38	0.07
TC-21-5-3-3-3	0.56	0.03	0.53	0.08	0.51	0.11	0.42	0.10	0.45	0.14	0.43	0.06
TC-21-5-4-3-3	0.53	0.04	0.56	0.12	0.49	0.13	0.41	0.09	0.42	0.09	0.43	0.08
TC-21-5-5-3-3	0.45	0.03	0.47	0.05	0.46	0.07	0.40	0.07	0.41	0.08	0.41	0.08
TC-21-5-1-4-1	0.51	0.02	0.52	0.02	0.51	0.03	0.51	0.02	0.51	0.02	0.51	0.02
TC-21-5-2-4-1	0.51	0.01	0.51	0.03	0.52	0.03	0.51	0.03	0.52	0.02	0.50	0.02
TC-21-5-3-4-1	0.24	0.02	0.28	0.01	0.32	0.01	0.34	0.01	0.36	0.01	0.38	0.02
TC-21-5-4-4-1	0.24	0.02	0.28	0.01	0.32	0.02	0.34	0.01	0.36	0.01	0.39	0.01
TC-21-5-5-4-1	0.51	0.03	0.51	0.02	0.50	0.02	0.51	0.02	0.52	0.03	0.51	0.03
TC-21-5-1-4-2	0.80	0.05	0.73	0.07	0.74	0.11	0.76	0.07	0.76	0.10	0.76	0.08
TC-21-5-2-4-2	0.78	0.04	0.80	0.05	0.78	0.12	0.79	0.09	0.79	0.09	0.77	0.08
TC-21-5-3-4-2	0.86	0.03	0.82	0.07	0.88	0.13	0.78	0.08	0.77	0.08	0.77	0.07
TC-21-5-4-4-2	0.92	0.03	0.90	0.11	0.86	0.14	0.86	0.19	0.78	0.09	0.80	0.10
TC-21-5-5-4-2	0.89	0.04	0.89	0.05	0.81	0.09	0.76	0.07	0.78	0.08	0.78	0.09
TC-21-5-1-4-3	1.06	0.05	0.96	0.10	0.93	0.13	0.99	0.10	1.01	0.12	0.97	0.15
TC-21-5-2-4-3	0.95	0.06	0.97	0.10	1.00	0.12	0.99	0.10	1.06	0.14	1.04	0.14
TC-21-5-3-4-3	1.12	0.08	1.11	0.09	1.13	0.19	1.00	0.10	0.98	0.12	1.10	0.21
TC-21-5-4-4-3	1.28	0.08	1.34	0.27	1.30	0.33	1.09	0.19	1.00	0.11	1.00	0.12
TC-21-5-5-4-3	1.10	0.04	1.08	0.09	1.07	0.10	1.00	0.16	0.99	0.13	0.99	0.12
TC-21-5-1-5-1	6.11	0.88	7.52	0.19	7.85	0.10	7.98	0.09	8.10	0.07	8.10	0.07
TC-21-5-2-5-1	8.22	0.08	8.21	0.08	8.20	0.10	8.19	0.09	8.19	0.09	8.20	0.09
TC-21-5-3-5-1	8.21	0.08	8.19	0.10	8.22	0.10	8.22	0.11	8.20	0.11	8.21	0.12
TC-21-5-4-5-1	8.16	0.11	8.15	0.10	8.15	0.11	8.13	0.11	8.15	0.09	8.14	0.10
TC-21-5-5-5-1	8.23	0.12	8.25	0.12	8.23	0.09	8.23	0.09	8.20	0.11	8.21	0.10
TC-21-5-1-5-2	9.21	0.12	9.14	0.16	9.13	0.14	9.16	0.23	9.12	0.14	9.16	0.18
TC-21-5-2-5-2	8.99	0.11	9.03	0.13	9.07	0.25	8.98	0.13	9.11	0.25	9.05	0.14
TC-21-5-3-5-2	9.17	0.12	9.22	0.16	9.28	0.20	9.27	0.23	9.21	0.16	9.23	0.23
TC-21-5-4-5-2	9.52	0.10	10.01	1.03	9.51	0.49	9.34	0.24	11.72	2.68	10.96	2.56
TC-21-5-5-5-2	9.22	0.12	9.22	0.16	9.18	0.25	9.06	0.28	8.98	0.12	9.06	0.21
TC-21-5-1-5-3	10.07	0.16	10.01	0.25	10.02	0.29	10.12	0.59	10.23	1.12	10.04	0.26
TC-21-5-2-5-3	9.74	0.09	9.80	0.18	10.09	0.84	10.04	0.64	9.93	0.36	10.08	0.55
TC-21-5-3-5-3	9.83	0.07	9.93	0.19	10.47	0.77	11.14	2.13	13.41	2.70	10.29	1.16
TC-21-5-4-5-3	11.47	0.40	11.27	1.45	11.06	1.42	10.29	0.90	10.07	0.29	10.27	0.38
TC-21-5-5-5-3	10.10	0.13	10.23	0.27	10.12	0.38	10.10	0.45	9.99	0.22	10.11	0.50

Table A.48: Time consumation (s) for edge-disjointness on TC-21-5 instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F	**BOT**
TC-21-10-1-3-1	389	389	389	389	252	252	252	252	252	252	**224**
TC-21-10-2-3-1	365	365	365	365	263	263	263	263	263	263	**241**
TC-21-10-3-3-1	445	445	445	445	278	278	278	278	278	278	**228**
TC-21-10-4-3-1	425	425	425	425	256	256	256	256	256	256	**235**
TC-21-10-5-3-1	405	405	405	405	273	273	273	273	273	273	**237**
TC-21-10-1-3-2	497	1538	591	683	1538	593	523	523	523	523	**392**
TC-21-10-2-3-2	515	1334	589	719	1334	505	596	596	596	596	**405**
TC-21-10-3-3-2	539	1248	710	801	1248	539	507	507	507	507	**402**
TC-21-10-4-3-2	599	1628	693	738	1628	655	574	574	574	574	**400**
TC-21-10-5-3-2	488	1776	667	693	1776	616	567	567	567	567	**408**
TC-21-10-1-3-3	776	2191	853	990	2191	866	834	834	834	834	**557**
TC-21-10-2-3-3	743	1785	804	1000	1785	779	917	917	917	917	**559**
TC-21-10-3-3-3	822	1658	1009	1106	1658	882	795	795	795	795	**563**
TC-21-10-4-3-3	823	2134	1042	1108	2134	860	921	921	921	921	**616**
TC-21-10-5-3-3	777	2364	887	997	2364	865	817	817	817	817	**591**
TC-21-10-1-4-1	389	389	389	389	252	252	252	252	252	252	**218**
TC-21-10-2-4-1	365	365	365	365	263	263	263	263	263	263	**229**
TC-21-10-3-4-1	445	445	445	445	278	278	278	278	278	278	**224**
TC-21-10-4-4-1	425	425	425	425	256	256	256	256	256	256	**222**
TC-21-10-5-4-1	405	405	405	405	273	273	273	273	273	273	**224**
TC-21-10-1-4-2	474	1704	574	683	1704	522	517	517	517	517	**359**
TC-21-10-2-4-2	444	1400	564	719	1400	488	523	523	523	523	**354**
TC-21-10-3-4-2	511	1356	655	801	1356	505	507	507	507	507	**360**
TC-21-10-4-4-2	544	1726	586	738	1726	548	507	507	507	507	**369**
TC-21-10-5-4-2	503	1910	620	693	1910	594	551	551	551	551	**371**
TC-21-10-1-4-3	646	2268	809	990	2268	666	792	792	792	792	**529**
TC-21-10-2-4-3	632	1976	810	1000	1976	748	796	796	796	796	**525**
TC-21-10-3-4-3	728	1791	928	1106	1791	728	732	732	732	732	**540**
TC-21-10-4-4-3	763	2134	961	1108	2134	911	778	778	778	778	**565**
TC-21-10-5-4-3	672	2332	927	997	2332	873	829	829	829	829	**562**
TC-21-10-1-5-1	389	389	389	389	252	252	252	252	252	252	**216**
TC-21-10-2-5-1	365	365	365	365	263	263	263	263	263	263	**228**
TC-21-10-3-5-1	445	445	445	445	278	278	278	278	278	278	**223**
TC-21-10-4-5-1	425	425	425	425	256	256	256	256	256	256	**222**
TC-21-10-5-5-1	405	405	405	405	273	273	273	273	273	273	**224**
TC-21-10-1-5-2	436	1638	510	683	1638	470	517	517	517	517	**333**
TC-21-10-2-5-2	404	1515	520	719	1515	444	518	518	518	518	**342**
TC-21-10-3-5-2	477	1474	567	801	1474	503	507	507	507	507	**341**
TC-21-10-4-5-2	518	1655	558	738	1655	538	507	507	507	507	**361**
TC-21-10-5-5-2	477	1735	562	693	1735	556	551	551	551	551	**361**
TC-21-10-1-5-3	642	2223	731	990	2223	642	737	737	737	737	**521**
TC-21-10-2-5-3	689	2138	717	1000	2138	715	754	754	754	754	**523**
TC-21-10-3-5-3	718	1850	882	1106	1850	746	732	732	732	732	**505**
TC-21-10-4-5-3	710	2181	824	1108	2181	786	748	748	748	748	**557**
TC-21-10-5-5-3	690	2311	845	997	2311	801	827	827	827	827	**547**

Table A.49: Results for edge-disjointness on TC-21-10 instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TC-21-10-1-3-1	0.07	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.01
TC-21-10-2-3-1	0.07	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01
TC-21-10-3-3-1	0.07	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01
TC-21-10-4-3-1	0.06	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.01
TC-21-10-5-3-1	0.08	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01
TC-21-10-1-3-2	0.56	0.08	0.34	0.01	0.08	0.34	0.01	0.01	0.01	0.02
TC-21-10-2-3-2	0.49	0.08	0.30	0.01	0.08	0.25	0.02	0.01	0.00	0.01
TC-21-10-3-3-2	0.53	0.07	0.42	0.01	0.08	0.27	0.01	0.01	0.01	0.01
TC-21-10-4-3-2	0.32	0.08	0.33	0.01	0.08	0.33	0.01	0.01	0.01	0.01
TC-21-10-5-3-2	0.56	0.08	0.41	0.02	0.08	0.39	0.01	0.01	0.01	0.01
TC-21-10-1-3-3	0.71	0.08	0.44	0.02	0.08	0.46	0.02	0.02	0.02	0.02
TC-21-10-2-3-3	0.62	0.07	0.43	0.02	0.08	0.38	0.01	0.02	0.02	0.01
TC-21-10-3-3-3	0.70	0.07	0.59	0.02	0.09	0.51	0.02	0.02	0.02	0.02
TC-21-10-4-3-3	0.47	0.07	0.47	0.02	0.06	0.42	0.01	0.02	0.02	0.02
TC-21-10-5-3-3	0.72	0.07	0.50	0.01	0.08	0.56	0.01	0.02	0.02	0.02
TC-21-10-1-4-1	0.99	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.01
TC-21-10-2-4-1	0.97	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01
TC-21-10-3-4-1	0.96	0.02	0.00	0.01	0.02	0.01	0.01	0.01	0.01	0.01
TC-21-10-4-4-1	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TC-21-10-5-4-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TC-21-10-1-4-2	1.76	1.02	1.28	0.01	1.02	1.25	0.02	0.02	0.02	0.02
TC-21-10-2-4-2	1.57	1.07	1.26	0.02	1.05	1.27	0.02	0.02	0.01	0.02
TC-21-10-3-4-2	1.41	1.01	1.28	0.02	0.96	1.27	0.02	0.01	0.02	0.01
TC-21-10-4-4-2	1.24	1.01	1.24	0.01	1.03	1.25	0.02	0.01	0.01	0.01
TC-21-10-5-4-2	1.54	1.06	1.40	0.01	1.05	1.31	0.02	0.02	0.01	0.02
TC-21-10-1-4-3	2.15	1.11	1.48	0.03	1.09	1.33	0.02	0.03	0.02	0.02
TC-21-10-2-4-3	1.93	1.16	1.49	0.02	1.09	1.40	0.03	0.03	0.03	0.01
TC-21-10-3-4-3	1.83	1.11	1.65	0.02	1.12	1.44	0.02	0.02	0.02	0.03
TC-21-10-4-4-3	1.57	1.14	1.46	0.02	1.12	1.47	0.03	0.02	0.03	0.02
TC-21-10-5-4-3	1.85	1.09	1.58	0.02	1.09	1.59	0.03	0.02	0.03	0.01
TC-21-10-1-5-1	16.18	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01
TC-21-10-2-5-1	16.33	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01
TC-21-10-3-5-1	16.29	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.02
TC-21-10-4-5-1	16.09	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.00	0.01
TC-21-10-5-5-1	1.83	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00
TC-21-10-1-5-2	19.13	17.30	17.47	0.02	17.42	17.42	0.02	0.02	0.02	0.02
TC-21-10-2-5-2	18.63	17.27	17.60	0.02	17.41	17.64	0.02	0.01	0.02	0.02
TC-21-10-3-5-2	18.08	17.42	17.85	0.01	17.28	17.67	0.02	0.02	0.02	0.03
TC-21-10-4-5-2	17.99	17.47	17.67	0.01	17.65	17.65	0.01	0.01	0.02	0.02
TC-21-10-5-5-2	18.07	17.59	18.08	0.02	17.30	18.22	0.02	0.01	0.01	0.02
TC-21-10-1-5-3	21.57	18.67	19.28	0.02	18.64	18.99	0.04	0.02	0.02	0.03
TC-21-10-2-5-3	20.47	18.82	19.49	0.03	18.78	19.51	0.03	0.03	0.02	0.02
TC-21-10-3-5-3	19.60	18.86	19.15	0.03	18.89	19.04	0.03	0.03	0.03	0.03
TC-21-10-4-5-3	19.43	18.45	18.83	0.02	18.36	18.78	0.03	0.03	0.03	0.03
TC-21-10-5-5-3	20.08	18.52	19.66	0.03	18.62	19.55	0.02	0.03	0.02	0.03

Table A.50: Time consumation (s) for edge-disjointness on TC-21-10 instances.

	VND with										
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F	**BOT**
TC-21-10-1-3-1	238	238	238	238	238	238	238	238	238	238	**224**
TC-21-10-2-3-1	241	241	241	241	244	244	244	244	244	244	**241**
TC-21-10-3-3-1	242	242	242	242	248	248	248	248	248	248	**228**
TC-21-10-4-3-1	250	250	250	250	248	248	248	248	248	248	**235**
TC-21-10-5-3-1	251	251	251	251	258	258	258	258	258	258	**237**
TC-21-10-1-3-2	494	487	476	463	487	500	445	445	445	445	**392**
TC-21-10-2-3-2	505	461	505	425	461	500	501	501	501	501	**405**
TC-21-10-3-3-2	498	648	498	497	648	498	447	447	447	447	**402**
TC-21-10-4-3-2	576	762	570	435	762	556	457	457	457	457	**400**
TC-21-10-5-3-2	486	737	506	429	737	486	465	465	465	465	**408**
TC-21-10-1-3-3	697	655	731	655	655	780	660	660	660	660	**557**
TC-21-10-2-3-3	739	716	775	676	716	775	644	644	644	644	**559**
TC-21-10-3-3-3	804	793	802	698	793	829	711	711	711	711	**563**
TC-21-10-4-3-3	771	885	765	669	885	796	687	687	687	687	**616**
TC-21-10-5-3-3	764	737	821	695	737	769	678	678	678	678	**591**
TC-21-10-1-4-1	238	238	238	238	238	238	238	238	238	238	**218**
TC-21-10-2-4-1	237	237	237	237	241	241	241	241	241	241	**229**
TC-21-10-3-4-1	244	244	244	244	240	240	240	240	240	240	**224**
TC-21-10-4-4-1	241	241	241	241	242	242	242	242	242	242	**222**
TC-21-10-5-4-1	230	230	230	230	238	238	238	238	238	238	**224**
TC-21-10-1-4-2	407	418	470	415	418	448	381	381	381	381	**359**
TC-21-10-2-4-2	424	453	489	390	453	467	446	446	446	446	**354**
TC-21-10-3-4-2	480	496	554	463	496	470	433	433	433	433	**360**
TC-21-10-4-4-2	497	488	493	424	488	483	461	461	461	461	**369**
TC-21-10-5-4-2	478	668	538	452	668	518	512	512	512	512	**371**
TC-21-10-1-4-3	609	646	619	642	646	609	693	693	693	693	**529**
TC-21-10-2-4-3	632	739	668	644	739	690	765	765	765	765	**525**
TC-21-10-3-4-3	623	826	735	688	826	623	732	732	732	732	**540**
TC-21-10-4-4-3	745	816	801	657	816	748	768	768	768	768	**565**
TC-21-10-5-4-3	665	823	735	732	823	733	737	737	737	737	**562**
TC-21-10-1-5-1	238	238	238	238	238	238	238	238	238	238	**216**
TC-21-10-2-5-1	236	236	236	236	228	228	228	228	228	228	**228**
TC-21-10-3-5-1	236	236	236	236	236	236	236	236	236	236	**223**
TC-21-10-4-5-1	241	241	241	241	242	242	242	242	242	242	**222**
TC-21-10-5-5-1	230	230	230	230	238	238	238	238	238	238	**224**
TC-21-10-1-5-2	385	694	425	405	694	385	367	367	367	367	**333**
TC-21-10-2-5-2	404	433	508	414	433	444	487	487	487	487	**342**
TC-21-10-3-5-2	462	675	512	438	675	494	419	419	419	419	**341**
TC-21-10-4-5-2	477	544	477	418	544	477	419	419	419	419	**361**
TC-21-10-5-5-2	465	766	490	451	766	480	512	512	512	512	**361**
TC-21-10-1-5-3	615	606	621	651	606	615	655	655	655	655	**521**
TC-21-10-2-5-3	644	682	691	642	682	644	701	701	701	701	**523**
TC-21-10-3-5-3	650	783	685	597	783	633	698	698	698	698	**505**
TC-21-10-4-5-3	699	763	744	649	763	744	688	688	688	688	**557**
TC-21-10-5-5-3	687	801	760	725	801	770	755	755	755	755	**547**

Table A.51: Results for edge-disjointness on TC-21-10 instances.

	VND with									
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TC-21-10-1-3-1	0.22	0.14	0.13	0.13	0.04	0.04	0.04	0.04	0.04	0.04
TC-21-10-2-3-1	0.23	0.17	0.17	0.16	0.05	0.06	0.06	0.06	0.07	0.06
TC-21-10-3-3-1	0.19	0.14	0.14	0.14	0.06	0.06	0.06	0.06	0.06	0.07
TC-21-10-4-3-1	0.20	0.13	0.14	0.14	0.06	0.06	0.06	0.06	0.06	0.06
TC-21-10-5-3-1	0.22	0.15	0.14	0.15	0.09	0.10	0.09	0.09	0.09	0.09
TC-21-10-1-3-2	0.67	0.41	0.52	0.26	0.39	0.59	0.16	0.16	0.16	0.16
TC-21-10-2-3-2	0.57	0.40	0.40	0.41	0.42	0.30	0.16	0.17	0.17	0.16
TC-21-10-3-3-2	0.65	0.27	0.69	0.28	0.26	0.44	0.13	0.14	0.14	0.13
TC-21-10-4-3-2	0.44	0.27	0.51	0.36	0.29	0.47	0.18	0.18	0.18	0.18
TC-21-10-5-3-2	0.68	0.44	0.59	0.31	0.41	0.53	0.20	0.20	0.20	0.20
TC-21-10-1-3-3	1.00	0.66	0.65	0.52	0.67	0.68	0.25	0.25	0.25	0.25
TC-21-10-2-3-3	0.76	0.57	0.59	0.51	0.57	0.48	0.34	0.33	0.33	0.33
TC-21-10-3-3-3	0.94	0.46	0.96	0.40	0.46	0.74	0.25	0.25	0.25	0.25
TC-21-10-4-3-3	0.64	0.43	0.93	0.53	0.43	0.61	0.43	0.43	0.43	0.43
TC-21-10-5-3-3	0.84	0.61	0.69	0.53	0.60	0.78	0.31	0.31	0.30	0.29
TC-21-10-1-4-1	1.12	0.16	0.16	0.16	0.05	0.05	0.05	0.05	0.05	0.05
TC-21-10-2-4-1	1.15	0.16	0.17	0.16	0.10	0.10	0.10	0.10	0.10	0.10
TC-21-10-3-4-1	1.09	0.15	0.14	0.14	0.08	0.08	0.09	0.09	0.09	0.09
TC-21-10-4-4-1	0.03	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.00
TC-21-10-5-4-1	0.02	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00
TC-21-10-1-4-2	1.92	1.64	1.49	0.41	1.67	1.42	0.26	0.26	0.27	0.26
TC-21-10-2-4-2	1.84	1.65	1.50	0.55	1.59	1.33	0.19	0.19	0.20	0.19
TC-21-10-3-4-2	1.62	1.48	1.58	0.42	1.49	1.37	0.21	0.21	0.22	0.22
TC-21-10-4-4-2	1.42	1.47	1.48	0.42	1.49	1.39	0.16	0.17	0.17	0.16
TC-21-10-5-4-2	1.74	1.40	1.68	0.36	1.41	1.53	0.19	0.20	0.20	0.19
TC-21-10-1-4-3	2.33	2.07	1.89	0.67	2.07	1.62	0.24	0.24	0.24	0.24
TC-21-10-2-4-3	1.99	1.96	1.91	0.85	1.94	1.54	0.13	0.13	0.13	0.13
TC-21-10-3-4-3	2.01	1.54	1.95	0.50	1.53	1.89	0.09	0.10	0.10	0.09
TC-21-10-4-4-3	1.78	1.91	1.96	0.69	1.88	2.03	0.13	0.13	0.13	0.13
TC-21-10-5-4-3	2.15	1.92	2.02	0.57	1.87	1.96	0.35	0.35	0.36	0.35
TC-21-10-1-5-1	16.57	0.18	0.18	0.19	0.06	0.05	0.05	0.06	0.06	0.06
TC-21-10-2-5-1	16.31	0.22	0.21	0.21	0.11	0.11	0.11	0.11	0.11	0.11
TC-21-10-3-5-1	16.54	0.17	0.17	0.17	0.13	0.13	0.13	0.13	0.12	0.13
TC-21-10-4-5-1	16.32	0.22	0.21	0.21	0.10	0.10	0.11	0.11	0.10	0.11
TC-21-10-5-5-1	4.81	0.08	0.08	0.09	0.04	0.05	0.04	0.05	0.05	0.04
TC-21-10-1-5-2	19.22	17.94	17.85	0.50	18.34	17.71	0.37	0.37	0.35	0.36
TC-21-10-2-5-2	18.25	17.70	17.62	0.61	18.07	17.78	0.11	0.11	0.10	0.10
TC-21-10-3-5-2	17.99	18.02	18.09	0.49	17.94	17.85	0.29	0.29	0.30	0.30
TC-21-10-4-5-2	18.11	18.20	18.16	0.54	18.29	17.93	0.34	0.33	0.34	0.34
TC-21-10-5-5-2	18.32	18.12	18.29	0.48	18.15	18.16	0.23	0.23	0.23	0.23
TC-21-10-1-5-3	21.74	20.24	19.64	0.78	20.25	19.16	0.42	0.42	0.41	0.41
TC-21-10-2-5-3	20.48	20.03	19.53	0.99	20.09	19.84	0.20	0.20	0.20	0.20
TC-21-10-3-5-3	19.75	19.06	20.10	0.96	19.33	19.76	0.28	0.28	0.28	0.27
TC-21-10-4-5-3	19.53	19.77	19.91	0.81	19.76	18.95	0.33	0.33	0.32	0.32
TC-21-10-5-5-3	20.26	19.94	19.92	0.84	19.71	19.58	0.46	0.46	0.46	0.46

Table A.52: Time consumation (s) for edge-disjointness on TC-21-10 instances.

	MSVND with												
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F		
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	**BOT**
TC-21-10-1-3-1	226.30	2.95	225.33	3.09	225.97	3.48	225.80	3.56	226.57	3.53	225.37	2.46	**224**
TC-21-10-2-3-1	241.13	0.35	241.03	0.18	241.13	0.35	241.03	0.18	241.10	0.31	241.00	0.00	**241**
TC-21-10-3-3-1	232.60	4.85	230.40	2.85	232.00	4.49	231.93	4.18	230.67	4.01	230.73	3.26	**228**
TC-21-10-4-3-1	246.00	6.05	245.30	6.59	245.30	6.13	245.37	7.02	244.73	6.12	245.67	7.05	**235**
TC-21-10-5-3-1	245.37	3.89	244.63	3.84	244.83	3.13	243.17	4.34	244.57	4.96	245.03	4.68	**237**
TC-21-10-1-3-2	487.00	0.00	487.00	0.00	487.00	0.00	426.40	12.30	428.87	6.64	427.53	9.53	**392**
TC-21-10-2-3-2	461.00	0.00	461.00	0.00	461.00	0.00	437.30	8.83	436.97	10.62	433.70	7.27	**405**
TC-21-10-3-3-2	648.00	0.00	648.00	0.00	648.00	0.00	428.47	16.39	423.77	11.42	421.03	7.47	**402**
TC-21-10-4-3-2	762.00	0.00	762.00	0.00	762.00	0.00	448.13	8.93	445.47	7.70	444.73	6.35	**400**
TC-21-10-5-3-2	737.00	0.00	737.00	0.00	737.00	0.00	430.23	3.14	429.23	4.07	428.53	4.60	**408**
TC-21-10-1-3-3	655.00	0.00	655.00	0.00	655.00	0.00	623.53	15.76	620.43	15.57	627.63	14.46	**557**
TC-21-10-2-3-3	716.00	0.00	716.00	0.00	716.00	0.00	626.13	13.03	624.43	15.59	630.63	15.52	**559**
TC-21-10-3-3-3	793.00	0.00	793.00	0.00	793.00	0.00	660.67	18.16	655.97	17.70	661.93	13.14	**563**
TC-21-10-4-3-3	885.00	0.00	885.00	0.00	885.00	0.00	663.20	8.04	658.77	7.65	661.63	7.33	**616**
TC-21-10-5-3-3	737.00	0.00	737.00	0.00	737.00	0.00	660.10	12.61	669.40	13.87	671.63	11.82	**591**
TC-21-10-1-4-1	223.47	3.49	224.23	4.33	223.13	3.59	223.40	3.40	223.03	2.91	224.43	4.04	**218**
TC-21-10-2-4-1	232.33	4.59	231.93	4.32	230.87	3.89	231.00	3.75	231.27	3.89	230.60	3.25	**229**
TC-21-10-3-4-1	229.07	5.27	226.87	3.85	229.07	5.22	229.73	5.32	228.73	4.88	229.33	4.82	**224**
TC-21-10-4-4-1	232.53	6.31	231.60	6.13	231.97	5.60	232.27	6.03	233.00	6.16	230.90	5.49	**222**
TC-21-10-5-4-1	229.10	2.17	229.07	1.64	228.97	2.01	228.80	1.86	228.47	0.86	229.77	2.57	**224**
TC-21-10-1-4-2	418.00	0.00	418.00	0.00	418.00	0.00	387.03	9.00	386.27	10.22	390.90	11.81	**359**
TC-21-10-2-4-2	453.00	0.00	453.00	0.00	453.00	0.00	431.40	14.19	426.67	15.24	430.33	14.08	**354**
TC-21-10-3-4-2	496.00	0.00	496.00	0.00	496.00	0.00	418.97	11.20	424.50	17.02	415.33	12.80	**360**
TC-21-10-4-4-2	488.00	0.00	488.00	0.00	488.00	0.00	415.70	20.91	417.27	19.37	424.60	20.62	**369**
TC-21-10-5-4-2	668.00	0.00	668.00	0.00	668.00	0.00	442.63	10.15	439.43	10.96	440.07	9.90	**371**
TC-21-10-1-4-3	646.00	0.00	646.00	0.00	646.00	0.00	613.40	20.32	619.07	18.45	617.07	16.76	**529**
TC-21-10-2-4-3	739.00	0.00	739.00	0.00	739.00	0.00	621.73	25.32	628.07	16.35	626.30	22.47	**525**
TC-21-10-3-4-3	826.00	0.00	826.00	0.00	826.00	0.00	635.10	15.37	633.63	20.36	635.07	18.47	**540**
TC-21-10-4-4-3	816.00	0.00	816.00	0.00	816.00	0.00	658.00	18.70	656.17	16.07	664.13	16.66	**565**
TC-21-10-5-4-3	823.00	0.00	823.00	0.00	823.00	0.00	689.80	13.81	687.17	11.54	687.80	13.28	**562**
TC-21-10-1-5-1	222.33	5.51	222.87	4.80	223.00	5.17	223.00	4.72	221.60	3.73	222.67	4.25	**216**
TC-21-10-2-5-1	228.00	0.00	228.27	1.46	228.53	2.03	228.00	0.00	228.80	2.44	228.80	2.44	**228**
TC-21-10-3-5-1	227.27	3.73	228.40	3.94	228.73	3.88	227.40	3.64	228.40	3.90	228.40	3.62	**223**
TC-21-10-4-5-1	233.43	6.15	231.60	5.76	230.63	4.82	231.57	5.69	231.70	6.24	232.00	5.30	**222**
TC-21-10-5-5-1	228.37	0.56	228.47	0.73	228.50	0.78	228.27	0.52	228.77	0.90	228.73	0.87	**224**
TC-21-10-1-5-2	694.00	0.00	694.00	0.00	694.00	0.00	366.60	9.02	369.87	6.89	368.20	10.11	**333**
TC-21-10-2-5-2	433.00	0.00	433.00	0.00	433.00	0.00	405.03	17.38	403.63	21.78	398.27	24.65	**342**
TC-21-10-3-5-2	675.00	0.00	675.00	0.00	675.00	0.00	404.40	20.30	411.63	12.29	410.33	16.72	**341**
TC-21-10-4-5-2	544.00	0.00	544.00	0.00	544.00	0.00	389.07	13.54	393.57	11.03	389.07	12.46	**361**
TC-21-10-5-5-2	766.00	0.00	766.00	0.00	766.00	0.00	418.87	11.26	419.57	11.89	420.27	11.16	**361**
TC-21-10-1-5-3	606.00	0.00	606.00	0.00	606.00	0.00	610.80	13.64	608.43	16.93	607.50	14.17	**521**
TC-21-10-2-5-3	682.00	0.00	682.00	0.00	682.00	0.00	625.17	16.40	615.20	24.67	614.77	17.33	**523**
TC-21-10-3-5-3	783.00	0.00	783.00	0.00	783.00	0.00	616.90	17.82	614.03	20.17	616.10	21.05	**505**
TC-21-10-4-5-3	763.00	0.00	763.00	0.00	763.00	0.00	644.00	23.72	642.83	17.48	645.13	19.08	**557**
TC-21-10-5-5-3	801.00	0.00	801.00	0.00	801.00	0.00	646.33	18.43	653.77	14.78	647.20	16.04	**547**

Table A.53: Results for edge-disjointness on TC-21-10 instances.

	MSVND with											
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TC-21-10-1-3-1	0.56	0.05	0.57	0.04	0.57	0.05	0.59	0.04	0.56	0.05	0.56	0.05
TC-21-10-2-3-1	0.55	0.07	0.55	0.07	0.56	0.05	0.58	0.08	0.57	0.05	0.56	0.07
TC-21-10-3-3-1	0.52	0.04	0.51	0.04	0.52	0.05	0.51	0.04	0.51	0.04	0.51	0.04
TC-21-10-4-3-1	0.48	0.04	0.48	0.05	0.46	0.05	0.48	0.05	0.46	0.05	0.48	0.05
TC-21-10-5-3-1	0.60	0.07	0.62	0.08	0.61	0.07	0.62	0.07	0.61	0.05	0.61	0.07
TC-21-10-1-3-2	3.62	0.02	3.61	0.03	3.61	0.03	1.72	0.12	1.72	0.13	1.73	0.11
TC-21-10-2-3-2	3.67	0.03	3.68	0.03	3.68	0.02	1.68	0.09	1.66	0.10	1.73	0.12
TC-21-10-3-3-2	2.30	0.02	2.30	0.03	2.30	0.02	1.36	0.11	1.40	0.12	1.44	0.11
TC-21-10-4-3-2	2.55	0.02	2.54	0.03	2.53	0.03	1.57	0.15	1.54	0.14	1.62	0.12
TC-21-10-5-3-2	3.87	0.03	3.86	0.03	3.86	0.02	1.94	0.15	1.96	0.16	1.94	0.16
TC-21-10-1-3-3	6.15	0.03	6.14	0.03	6.15	0.03	3.10	0.29	3.01	0.31	2.96	0.21
TC-21-10-2-3-3	5.07	0.03	5.07	0.03	5.08	0.03	2.80	0.27	2.88	0.20	2.74	0.22
TC-21-10-3-3-3	4.07	0.03	4.08	0.03	4.08	0.02	2.52	0.27	2.49	0.21	2.51	0.18
TC-21-10-4-3-3	3.91	0.03	3.91	0.03	3.90	0.03	2.95	0.23	2.99	0.22	2.91	0.22
TC-21-10-5-3-3	5.53	0.02	5.52	0.03	5.52	0.03	3.11	0.28	3.08	0.27	3.15	0.35
TC-21-10-1-4-1	0.75	0.07	0.76	0.07	0.76	0.06	0.74	0.07	0.74	0.08	0.75	0.06
TC-21-10-2-4-1	0.71	0.07	0.69	0.06	0.73	0.06	0.72	0.05	0.71	0.06	0.70	0.05
TC-21-10-3-4-1	0.61	0.06	0.65	0.05	0.61	0.05	0.64	0.06	0.64	0.06	0.62	0.06
TC-21-10-4-4-1	0.12	0.05	0.24	0.03	0.33	0.03	0.39	0.03	0.44	0.03	0.48	0.04
TC-21-10-5-4-1	0.12	0.05	0.27	0.04	0.38	0.04	0.46	0.04	0.51	0.04	0.55	0.04
TC-21-10-1-4-2	14.89	0.09	14.91	0.07	14.88	0.11	2.19	0.19	2.09	0.26	2.12	0.25
TC-21-10-2-4-2	14.42	0.12	14.45	0.10	14.44	0.09	1.68	0.20	1.67	0.16	1.65	0.17
TC-21-10-3-4-2	13.19	0.12	13.18	0.09	13.21	0.07	1.50	0.16	1.44	0.15	1.54	0.19
TC-21-10-4-4-2	13.41	0.09	13.40	0.07	13.43	0.10	1.42	0.23	1.43	0.22	1.35	0.14
TC-21-10-5-4-2	12.96	0.11	13.00	0.12	12.98	0.09	1.71	0.20	1.66	0.18	1.68	0.18
TC-21-10-1-4-3	18.82	0.11	18.85	0.12	18.84	0.10	3.56	0.43	3.52	0.55	3.46	0.27
TC-21-10-2-4-3	17.57	0.09	17.57	0.10	17.59	0.10	3.67	0.39	3.59	0.37	3.54	0.52
TC-21-10-3-4-3	13.73	0.12	13.75	0.10	13.74	0.11	2.86	0.43	2.72	0.38	2.70	0.41
TC-21-10-4-4-3	16.77	0.10	16.75	0.08	16.77	0.13	2.83	0.33	2.95	0.44	2.73	0.31
TC-21-10-5-4-3	17.13	0.10	17.12	0.10	17.12	0.10	3.14	0.48	3.11	0.39	3.07	0.40
TC-21-10-1-5-1	0.89	0.09	0.90	0.06	0.89	0.08	0.91	0.06	0.88	0.07	0.89	0.08
TC-21-10-2-5-1	0.96	0.07	0.96	0.06	0.96	0.07	0.97	0.07	0.95	0.07	0.96	0.08
TC-21-10-3-5-1	0.81	0.06	0.77	0.06	0.80	0.07	0.81	0.06	0.79	0.06	0.80	0.08
TC-21-10-4-5-1	0.86	0.05	0.84	0.06	0.86	0.07	0.86	0.06	0.84	0.07	0.85	0.06
TC-21-10-5-5-1	0.48	0.06	0.63	0.06	0.74	0.06	0.79	0.06	0.83	0.05	0.86	0.06
TC-21-10-1-5-2	162.71	0.56	162.71	0.52	162.76	0.60	3.29	0.28	3.24	0.25	3.24	0.27
TC-21-10-2-5-2	162.86	0.41	163.16	0.50	172.02	23.12	2.47	0.21	2.47	0.26	2.53	0.25
TC-21-10-3-5-2	164.06	7.90	191.58	26.16	177.14	24.40	2.24	0.23	2.27	0.20	2.24	0.18
TC-21-10-4-5-2	169.12	12.01	168.37	13.89	166.67	7.00	2.55	0.27	2.58	0.26	2.58	0.22
TC-21-10-5-5-2	172.35	23.81	167.84	9.51	164.60	3.44	2.70	0.22	2.67	0.17	2.74	0.21
TC-21-10-1-5-3	181.03	0.50	181.19	0.60	181.47	0.71	5.35	0.40	5.42	0.51	5.19	0.48
TC-21-10-2-5-3	180.04	0.46	179.85	0.52	179.96	0.56	4.43	0.46	4.43	0.56	4.51	0.56
TC-21-10-3-5-3	174.90	4.95	174.43	3.24	176.53	11.48	3.94	0.45	3.86	0.50	4.00	0.56
TC-21-10-4-5-3	194.19	33.10	186.99	24.73	176.37	0.55	3.99	0.51	4.18	0.45	4.03	0.41
TC-21-10-5-5-3	178.90	2.00	190.82	17.05	185.08	10.48	4.40	0.50	4.24	0.37	4.27	0.43

Table A.54: Time consumation (s) for edge-disjointness on TC-21-10 instances.

	GRASP												
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$		
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	**BOT**
TC-21-10-1-3-1	238.00	0.00	238.00	0.00	238.00	0.00	238.00	0.00	238.00	0.00	238.00	0.00	**224**
TC-21-10-2-3-1	241.00	0.00	241.00	0.00	241.00	0.00	241.00	0.00	241.00	0.00	241.00	0.00	**241**
TC-21-10-3-3-1	242.00	0.00	242.00	0.00	242.00	0.00	242.00	0.00	242.00	0.00	242.00	0.00	**228**
TC-21-10-4-3-1	250.00	0.00	250.00	0.00	250.00	0.00	250.00	0.00	250.00	0.00	250.00	0.00	**235**
TC-21-10-5-3-1	251.00	0.00	251.00	0.00	251.00	0.00	251.00	0.00	251.00	0.00	251.00	0.00	**237**
TC-21-10-1-3-2	457.57	20.55	474.53	34.27	525.30	47.32	566.20	55.75	632.77	83.87	640.47	89.33	**392**
TC-21-10-2-3-2	497.80	5.98	487.70	18.65	524.37	35.26	584.70	73.82	637.73	60.90	648.10	76.55	**405**
TC-21-10-3-3-2	498.00	0.00	510.70	34.64	529.00	53.06	583.27	58.48	628.97	108.63	648.90	95.45	**402**
TC-21-10-4-3-2	531.47	36.59	514.13	23.34	551.27	44.74	630.60	74.22	653.27	80.32	662.53	77.02	**400**
TC-21-10-5-3-2	480.33	10.00	494.07	27.80	508.30	43.78	614.27	58.50	636.07	71.30	648.53	86.79	**408**
TC-21-10-1-3-3	664.80	15.32	715.77	41.38	766.87	63.48	842.40	81.52	873.47	89.29	969.90	105.65	**557**
TC-21-10-2-3-3	734.17	18.23	704.00	40.91	774.50	50.60	868.43	111.93	915.20	110.12	952.13	93.85	**559**
TC-21-10-3-3-3	765.60	36.53	748.13	27.16	779.13	60.85	874.20	94.09	938.57	121.49	980.80	147.83	**563**
TC-21-10-4-3-3	763.10	35.41	751.90	34.22	803.73	55.54	908.30	94.36	976.43	95.31	1008.40	104.97	**616**
TC-21-10-5-3-3	738.60	26.86	749.33	38.30	767.30	47.54	878.77	49.25	979.40	91.35	954.60	97.81	**591**
TC-21-10-1-4-1	238.00	0.00	238.00	0.00	238.00	0.00	238.00	0.00	238.00	0.00	238.00	0.00	**218**
TC-21-10-2-4-1	237.00	0.00	237.00	0.00	237.00	0.00	237.00	0.00	237.00	0.00	237.00	0.00	**229**
TC-21-10-3-4-1	244.00	0.00	244.00	0.00	244.00	0.00	244.00	0.00	244.00	0.00	244.00	0.00	**224**
TC-21-10-4-4-1	241.00	0.00	241.00	0.00	241.00	0.00	241.00	0.00	241.00	0.00	241.00	0.00	**222**
TC-21-10-5-4-1	230.00	0.00	230.00	0.00	230.00	0.00	230.00	0.00	230.00	0.00	230.00	0.00	**224**
TC-21-10-1-4-2	439.40	22.49	443.17	29.19	545.60	57.92	630.87	90.71	651.27	94.57	670.73	100.48	**359**
TC-21-10-2-4-2	441.60	14.62	451.63	18.86	514.70	61.32	607.87	71.01	636.33	99.37	676.77	83.33	**354**
TC-21-10-3-4-2	455.30	20.76	464.97	27.22	542.80	53.06	606.43	69.90	686.97	101.27	714.57	74.28	**360**
TC-21-10-4-4-2	489.53	7.10	475.67	35.35	534.70	66.88	649.87	97.99	717.93	120.64	718.37	134.39	**369**
TC-21-10-5-4-2	480.43	10.45	460.40	27.37	494.87	36.72	596.73	88.52	666.03	83.03	738.10	109.03	**371**
TC-21-10-1-4-3	622.13	19.33	675.07	43.68	760.87	67.16	930.53	107.04	1052.10	136.20	1002.47	164.26	**529**
TC-21-10-2-4-3	646.83	20.69	658.93	38.89	748.13	72.34	854.77	115.38	955.10	115.98	1011.80	144.42	**525**
TC-21-10-3-4-3	658.43	23.66	676.57	31.59	801.73	83.40	914.87	100.41	981.00	111.56	1020.80	191.56	**540**
TC-21-10-4-4-3	728.13	24.80	717.90	37.17	801.57	55.78	995.30	116.90	1028.60	115.49	1072.53	156.73	**565**
TC-21-10-5-4-3	662.73	16.41	686.10	27.52	725.30	45.33	866.90	76.86	1022.97	134.25	1030.27	123.18	**562**
TC-21-10-1-5-1	238.00	0.00	238.00	0.00	238.00	0.00	238.00	0.00	238.00	0.00	238.00	0.00	**216**
TC-21-10-2-5-1	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00	**228**
TC-21-10-3-5-1	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00	236.00	0.00	**223**
TC-21-10-4-5-1	241.00	0.00	241.00	0.00	241.00	0.00	241.00	0.00	241.00	0.00	241.00	0.00	**222**
TC-21-10-5-5-1	230.00	0.00	230.00	0.00	230.00	0.00	230.00	0.00	230.00	0.00	230.00	0.00	**224**
TC-21-10-1-5-2	395.67	10.20	428.13	35.96	535.43	67.00	622.50	93.77	679.27	94.09	684.93	134.58	**333**
TC-21-10-2-5-2	412.93	9.74	432.40	26.67	522.70	50.05	583.80	82.46	697.20	116.72	706.57	134.94	**342**
TC-21-10-3-5-2	451.80	13.75	459.07	35.87	535.77	72.10	621.83	92.37	681.63	114.27	666.37	109.51	**341**
TC-21-10-4-5-2	457.60	36.38	451.47	43.49	550.03	75.12	650.57	105.40	750.47	122.23	738.40	126.10	**361**
TC-21-10-5-5-2	447.27	14.18	447.40	28.16	503.00	45.05	615.27	81.91	685.97	90.24	719.57	102.33	**361**
TC-21-10-1-5-3	624.20	11.46	680.10	46.75	752.37	77.83	942.37	119.79	958.80	121.28	1047.80	99.66	**521**
TC-21-10-2-5-3	639.47	29.30	642.87	31.69	748.87	64.43	858.47	95.64	969.80	135.22	1023.00	136.73	**523**
TC-21-10-3-5-3	651.60	12.70	648.67	30.55	780.23	67.29	930.60	117.83	987.97	147.09	966.23	141.66	**505**
TC-21-10-4-5-3	704.70	4.41	703.67	37.69	793.63	81.87	968.60	102.17	1080.83	145.26	1081.77	165.22	**557**
TC-21-10-5-5-3	690.60	5.59	687.33	25.93	736.30	54.45	853.57	91.79	979.43	113.71	1049.70	140.86	**547**

Table A.55: Results for edge-disjointness on TC-21-10 instances.

	GRASP											
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TC-21-10-1-3-1	0.20	0.01	0.20	0.01	0.20	0.01	0.20	0.01	0.20	0.01	0.20	0.01
TC-21-10-2-3-1	0.23	0.01	0.22	0.01	0.23	0.01	0.22	0.01	0.23	0.01	0.23	0.01
TC-21-10-3-3-1	0.20	0.01	0.20	0.01	0.20	0.01	0.20	0.01	0.20	0.01	0.20	0.01
TC-21-10-4-3-1	0.20	0.01	0.20	0.01	0.20	0.01	0.21	0.01	0.20	0.01	0.20	0.01
TC-21-10-5-3-1	0.21	0.01	0.21	0.01	0.22	0.01	0.21	0.01	0.21	0.01	0.22	0.01
TC-21-10-1-3-2	0.70	0.07	0.75	0.12	0.67	0.14	0.67	0.16	0.64	0.12	0.64	0.12
TC-21-10-2-3-2	0.58	0.03	0.65	0.13	0.59	0.15	0.60	0.17	0.60	0.12	0.62	0.13
TC-21-10-3-3-2	0.71	0.02	0.75	0.11	0.70	0.19	0.59	0.12	0.60	0.10	0.62	0.14
TC-21-10-4-3-2	0.49	0.05	0.52	0.07	0.59	0.12	0.61	0.15	0.62	0.14	0.63	0.13
TC-21-10-5-3-2	0.63	0.04	0.61	0.09	0.66	0.12	0.52	0.09	0.61	0.13	0.60	0.13
TC-21-10-1-3-3	0.90	0.08	0.96	0.15	0.92	0.20	0.98	0.26	0.96	0.14	0.92	0.19
TC-21-10-2-3-3	0.76	0.05	0.88	0.18	0.86	0.17	0.87	0.19	0.96	0.17	0.91	0.23
TC-21-10-3-3-3	0.88	0.05	0.99	0.16	1.08	0.30	0.94	0.23	0.85	0.15	0.95	0.16
TC-21-10-4-3-3	0.67	0.07	0.75	0.12	0.91	0.21	0.89	0.22	0.93	0.18	0.90	0.22
TC-21-10-5-3-3	0.80	0.02	0.83	0.10	0.93	0.13	0.92	0.22	0.91	0.18	0.91	0.18
TC-21-10-1-4-1	1.11	0.03	1.11	0.03	1.11	0.03	1.12	0.04	1.11	0.03	1.11	0.03
TC-21-10-2-4-1	1.12	0.03	1.13	0.03	1.12	0.03	1.11	0.03	1.11	0.03	1.12	0.04
TC-21-10-3-4-1	1.10	0.04	1.11	0.04	1.11	0.03	1.10	0.04	1.10	0.03	1.10	0.03
TC-21-10-4-4-1	0.88	0.03	0.94	0.02	0.98	0.02	1.00	0.02	1.04	0.02	1.04	0.02
TC-21-10-5-4-1	0.85	0.03	0.90	0.03	0.94	0.02	0.96	0.02	0.99	0.02	1.01	0.03
TC-21-10-1-4-2	1.93	0.09	2.12	0.29	1.78	0.33	1.59	0.14	1.69	0.20	1.63	0.18
TC-21-10-2-4-2	1.80	0.06	1.84	0.29	1.66	0.23	1.68	0.20	1.64	0.15	1.63	0.21
TC-21-10-3-4-2	1.66	0.09	1.69	0.12	1.85	0.59	1.66	0.15	1.61	0.16	1.61	0.14
TC-21-10-4-4-2	1.39	0.04	1.52	0.09	1.75	0.30	1.72	0.29	1.62	0.15	1.67	0.18
TC-21-10-5-4-2	1.67	0.06	1.70	0.10	1.74	0.18	1.70	0.22	1.66	0.24	1.65	0.16
TC-21-10-1-4-3	2.36	0.11	2.59	0.53	2.52	0.63	2.30	0.43	2.25	0.38	2.28	0.40
TC-21-10-2-4-3	2.12	0.08	2.47	0.45	2.27	0.58	2.13	0.26	2.30	0.49	2.24	0.32
TC-21-10-3-4-3	2.01	0.08	2.14	0.13	2.39	0.46	2.27	0.45	2.14	0.42	2.19	0.32
TC-21-10-4-4-3	1.83	0.07	1.93	0.18	2.21	0.33	2.17	0.38	2.27	0.53	2.10	0.25
TC-21-10-5-4-3	2.08	0.09	2.03	0.17	2.25	0.25	2.21	0.37	2.13	0.24	2.09	0.34
TC-21-10-1-5-1	16.47	0.20	16.45	0.13	16.44	0.17	16.48	0.17	16.58	0.32	17.64	2.01
TC-21-10-2-5-1	16.56	0.16	16.52	0.14	16.50	0.15	16.51	0.20	16.54	0.16	17.15	1.62
TC-21-10-3-5-1	16.47	0.15	16.65	0.37	16.46	0.14	16.75	0.78	16.55	0.22	24.91	3.07
TC-21-10-4-5-1	16.35	0.15	16.35	0.12	16.38	0.14	16.39	0.11	16.41	0.12	16.40	0.15
TC-21-10-5-5-1	15.61	0.41	16.24	0.11	16.42	0.14	16.41	0.13	16.45	0.16	16.40	0.12
TC-21-10-1-5-2	19.26	0.29	19.50	0.90	18.70	1.25	18.46	0.80	18.25	0.44	18.15	0.31
TC-21-10-2-5-2	19.05	2.08	18.95	1.10	18.44	0.45	18.17	0.33	18.11	0.27	18.23	0.51
TC-21-10-3-5-2	19.56	3.24	18.27	0.25	19.85	3.57	19.82	3.09	18.49	0.70	20.05	2.55
TC-21-10-4-5-2	19.94	3.88	19.09	2.47	20.64	3.69	18.50	0.41	20.19	4.05	18.86	2.11
TC-21-10-5-5-2	18.55	0.22	19.04	1.28	20.88	1.51	19.11	1.42	18.38	0.41	18.31	0.37
TC-21-10-1-5-3	21.59	0.41	22.52	1.87	21.42	2.08	20.97	1.71	20.25	0.67	20.88	1.60
TC-21-10-2-5-3	20.71	0.21	22.33	2.41	20.91	1.15	20.48	0.56	20.48	0.70	20.89	0.90
TC-21-10-3-5-3	19.78	0.19	19.95	0.51	22.33	4.01	20.96	2.64	20.41	1.53	20.38	1.17
TC-21-10-4-5-3	19.58	0.17	19.86	0.54	21.39	2.57	20.84	2.15	20.15	0.84	20.35	0.76
TC-21-10-5-5-3	21.08	3.03	20.82	2.46	21.93	3.26	24.18	3.89	22.25	1.94	23.00	3.29

Table A.56: Time consumation (s) for edge-disjointness on TC-21-10 instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F	**BOT**
TE-21-5-1-3-1	374	374	374	374	238	238	238	238	238	238	**200**
TE-21-5-2-3-1	304	304	304	304	174	174	174	174	174	174	**157**
TE-21-5-3-3-1	328	328	328	328	224	224	224	224	224	224	**193**
TE-21-5-4-3-1	371	371	371	371	218	218	218	218	218	218	**183**
TE-21-5-5-3-1	381	381	381	381	268	268	268	268	268	268	**224**
TE-21-5-1-3-2	514	971	606	652	971	582	497	497	497	497	**335**
TE-21-5-2-3-2	346	871	456	503	871	434	348	348	348	348	**267**
TE-21-5-3-3-2	432	1340	539	614	1340	471	469	469	469	469	**337**
TE-21-5-4-3-2	376	1203	523	681	1203	479	434	434	434	434	**330**
TE-21-5-5-3-2	556	1202	609	726	1202	572	542	542	542	542	**384**
TE-21-5-1-3-3	679	1283	870	900	1283	755	725	725	725	725	**479**
TE-21-5-2-3-3	581	1192	697	776	1192	645	542	542	542	542	**383**
TE-21-5-3-3-3	620	1758	758	869	1758	688	699	699	699	699	**449**
TE-21-5-4-3-3	610	1505	751	960	1505	750	607	607	607	607	**463**
TE-21-5-5-3-3	813	1447	948	1098	1447	857	870	870	870	870	**526**
TE-21-5-1-4-1	374	374	374	374	238	238	238	238	238	238	**199**
TE-21-5-2-4-1	304	304	304	304	174	174	174	174	174	174	**149**
TE-21-5-3-4-1	328	328	328	328	224	224	224	224	224	224	**190**
TE-21-5-4-4-1	371	371	371	371	218	218	218	218	218	218	**180**
TE-21-5-5-4-1	381	381	381	381	268	268	268	268	268	268	**211**
TE-21-5-1-4-2	423	994	471	652	994	423	439	439	439	439	**328**
TE-21-5-2-4-2	361	879	433	503	879	433	385	385	385	385	**257**
TE-21-5-3-4-2	399	1402	461	614	1402	419	422	422	422	422	**287**
TE-21-5-4-4-2	356	1253	422	681	1253	384	416	416	416	416	**305**
TE-21-5-5-4-2	495	1193	612	726	1193	495	521	521	521	521	**353**
TE-21-5-1-4-3	645	1277	798	900	1277	691	662	662	662	662	**476**
TE-21-5-2-4-3	598	1231	706	776	1231	684	616	616	616	616	**383**
TE-21-5-3-4-3	598	1840	710	869	1840	640	631	631	631	631	**449**
TE-21-5-4-4-3	564	1772	664	960	1772	598	585	585	585	585	**463**
TE-21-5-5-4-3	783	1524	944	1098	1524	797	821	821	821	821	**525**
TE-21-5-1-5-1	374	374	374	374	238	238	238	238	238	238	**199**
TE-21-5-2-5-1	304	304	304	304	174	174	174	174	174	174	**149**
TE-21-5-3-5-1	328	328	328	328	224	224	224	224	224	224	**189**
TE-21-5-4-5-1	371	371	371	371	218	218	218	218	218	218	**180**
TE-21-5-5-5-1	381	381	381	381	268	268	268	268	268	268	**211**
TE-21-5-1-5-2	424	983	486	652	983	434	438	438	438	438	**288**
TE-21-5-2-5-2	357	1009	475	503	1009	447	385	385	385	385	**226**
TE-21-5-3-5-2	387	1525	427	614	1525	429	422	422	422	422	**267**
TE-21-5-4-5-2	386	1454	414	681	1454	414	416	416	416	416	**285**
TE-21-5-5-5-2	533	1327	565	726	1327	533	521	521	521	521	**308**
TE-21-5-1-5-3	610	1312	726	900	1312	688	653	653	653	653	**475**
TE-21-5-2-5-3	488	1519	650	776	1519	650	616	616	616	616	**383**
TE-21-5-3-5-3	632	2013	674	869	2013	646	631	631	631	631	**449**
TE-21-5-4-5-3	606	2022	636	960	2022	616	585	585	585	585	**463**
TE-21-5-5-5-3	704	1713	805	1098	1713	684	816	816	816	816	**518**

Table A.57: Results for edge-disjointness on TE-21-5 instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TE-21-5-1-3-1	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
TE-21-5-2-3-1	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TE-21-5-3-3-1	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TE-21-5-4-3-1	0.03	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
TE-21-5-5-3-1	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
TE-21-5-1-3-2	0.69	0.03	0.42	0.00	0.04	0.44	0.01	0.01	0.01	0.00
TE-21-5-2-3-2	0.42	0.04	0.28	0.00	0.04	0.27	0.00	0.00	0.01	0.01
TE-21-5-3-3-2	0.34	0.03	0.23	0.01	0.04	0.26	0.01	0.01	0.00	0.01
TE-21-5-4-3-2	0.71	0.04	0.43	0.01	0.04	0.35	0.00	0.00	0.01	0.00
TE-21-5-5-3-2	0.38	0.05	0.33	0.00	0.03	0.30	0.00	0.00	0.01	0.01
TE-21-5-1-3-3	0.83	0.04	0.55	0.00	0.03	0.49	0.01	0.01	0.00	0.01
TE-21-5-2-3-3	0.61	0.04	0.41	0.00	0.04	0.43	0.01	0.01	0.01	0.00
TE-21-5-3-3-3	0.48	0.04	0.32	0.01	0.05	0.34	0.01	0.00	0.01	0.01
TE-21-5-4-3-3	0.97	0.05	0.48	0.01	0.04	0.37	0.00	0.01	0.01	0.00
TE-21-5-5-3-3	0.51	0.04	0.44	0.01	0.02	0.40	0.01	0.01	0.01	0.00
TE-21-5-1-4-1	0.51	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00
TE-21-5-2-4-1	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
TE-21-5-3-4-1	0.46	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TE-21-5-4-4-1	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
TE-21-5-5-4-1	0.49	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01
TE-21-5-1-4-2	1.07	0.51	0.85	0.00	0.50	0.69	0.01	0.01	0.01	0.00
TE-21-5-2-4-2	0.79	0.51	0.75	0.01	0.54	0.65	0.00	0.00	0.01	0.01
TE-21-5-3-4-2	0.73	0.51	0.63	0.00	0.51	0.62	0.01	0.01	0.00	0.00
TE-21-5-4-4-2	1.37	0.52	0.97	0.01	0.50	0.66	0.01	0.01	0.01	0.01
TE-21-5-5-4-2	0.79	0.52	0.76	0.01	0.51	0.71	0.01	0.00	0.01	0.01
TE-21-5-1-4-3	1.74	0.53	0.95	0.00	0.50	0.99	0.01	0.01	0.00	0.01
TE-21-5-2-4-3	0.92	0.57	0.83	0.01	0.57	0.84	0.00	0.01	0.01	0.01
TE-21-5-3-4-3	0.92	0.55	0.76	0.01	0.55	0.79	0.01	0.01	0.01	0.01
TE-21-5-4-4-3	2.43	0.58	1.04	0.01	0.53	0.78	0.01	0.00	0.01	0.01
TE-21-5-5-4-3	0.91	0.55	0.90	0.01	0.54	0.86	0.01	0.01	0.01	0.01
TE-21-5-1-5-1	8.15	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
TE-21-5-2-5-1	8.09	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00
TE-21-5-3-5-1	8.15	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
TE-21-5-4-5-1	8.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00
TE-21-5-5-5-1	7.99	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
TE-21-5-1-5-2	9.80	8.71	9.28	0.01	8.69	8.93	0.00	0.01	0.01	0.01
TE-21-5-2-5-2	9.21	8.66	9.01	0.01	8.81	9.02	0.00	0.01	0.01	0.01
TE-21-5-3-5-2	8.93	8.64	8.94	0.00	8.90	8.71	0.01	0.01	0.01	0.00
TE-21-5-4-5-2	10.85	8.68	9.37	0.01	8.78	9.00	0.01	0.01	0.01	0.01
TE-21-5-5-5-2	8.91	8.76	8.94	0.01	8.70	8.91	0.01	0.01	0.00	0.01
TE-21-5-1-5-3	13.88	9.35	10.09	0.01	9.23	9.88	0.02	0.02	0.02	0.01
TE-21-5-2-5-3	9.66	9.40	9.72	0.02	9.44	9.74	0.01	0.00	0.01	0.01
TE-21-5-3-5-3	9.94	9.19	9.55	0.01	9.26	9.67	0.01	0.01	0.00	0.01
TE-21-5-4-5-3	19.43	9.24	10.19	0.02	9.43	9.74	0.01	0.01	0.01	0.00
TE-21-5-5-5-3	10.04	9.34	9.67	0.01	9.49	9.70	0.02	0.02	0.01	0.01

Table A.58: Time consumation (s) for edge-disjointness on TE-21-5 instances.

	VND with										
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F	**BOT**
TE-21-5-1-3-1	200	200	200	200	222	222	222	222	222	222	**200**
TE-21-5-2-3-1	159	159	159	159	168	168	168	168	168	168	**157**
TE-21-5-3-3-1	217	217	217	217	217	217	217	217	217	217	**193**
TE-21-5-4-3-1	216	216	216	216	202	202	202	202	202	202	**183**
TE-21-5-5-3-1	224	224	224	224	268	268	268	268	268	268	**224**
TE-21-5-1-3-2	484	388	435	390	388	435	471	471	471	471	**335**
TE-21-5-2-3-2	319	303	319	303	303	319	348	348	348	348	**267**
TE-21-5-3-3-2	385	349	385	349	349	385	389	389	389	389	**337**
TE-21-5-4-3-2	368	415	429	368	415	421	368	368	368	368	**330**
TE-21-5-5-3-2	462	519	462	440	519	503	468	468	468	468	**384**
TE-21-5-1-3-3	649	694	678	594	694	678	653	653	653	653	**479**
TE-21-5-2-3-3	542	441	542	383	441	510	528	528	528	528	**383**
TE-21-5-3-3-3	590	519	607	519	519	607	609	609	609	609	**449**
TE-21-5-4-3-3	568	631	649	564	631	653	541	541	541	541	**463**
TE-21-5-5-3-3	761	715	693	610	715	777	654	654	654	654	**526**
TE-21-5-1-4-1	200	200	200	200	208	208	208	208	208	208	**199**
TE-21-5-2-4-1	159	159	159	159	149	149	149	149	149	149	**149**
TE-21-5-3-4-1	191	191	191	191	191	191	191	191	191	191	**190**
TE-21-5-4-4-1	200	200	200	200	202	202	202	202	202	202	**180**
TE-21-5-5-4-1	219	219	219	219	244	244	244	244	244	244	**211**
TE-21-5-1-4-2	406	470	446	404	470	406	439	439	439	439	**328**
TE-21-5-2-4-2	309	272	280	311	272	366	311	311	311	311	**257**
TE-21-5-3-4-2	381	518	381	313	518	404	383	383	383	383	**287**
TE-21-5-4-4-2	333	470	355	406	470	355	408	408	408	408	**305**
TE-21-5-5-4-2	449	524	454	374	524	449	521	521	521	521	**353**
TE-21-5-1-4-3	597	580	625	622	580	610	622	622	622	622	**476**
TE-21-5-2-4-3	507	459	499	388	459	468	478	478	478	478	**383**
TE-21-5-3-4-3	593	673	584	547	673	593	547	547	547	547	**449**
TE-21-5-4-4-3	493	554	546	551	554	546	537	537	537	537	**463**
TE-21-5-5-4-3	680	743	680	667	743	680	688	688	688	688	**525**
TE-21-5-1-5-1	200	200	200	200	208	208	208	208	208	208	**199**
TE-21-5-2-5-1	159	159	159	159	149	149	149	149	149	149	**149**
TE-21-5-3-5-1	191	191	191	191	191	191	191	191	191	191	**189**
TE-21-5-4-5-1	200	200	200	200	202	202	202	202	202	202	**180**
TE-21-5-5-5-1	219	219	219	219	244	244	244	244	244	244	**211**
TE-21-5-1-5-2	359	390	359	372	390	359	438	438	438	438	**288**
TE-21-5-2-5-2	300	226	301	298	226	360	288	288	288	288	**226**
TE-21-5-3-5-2	368	344	385	313	344	380	363	363	363	363	**267**
TE-21-5-4-5-2	360	448	355	384	448	355	394	394	394	394	**285**
TE-21-5-5-5-2	420	462	419	368	462	416	471	471	471	471	**308**
TE-21-5-1-5-3	563	580	641	594	580	617	605	605	605	605	**475**
TE-21-5-2-5-3	462	436	471	388	436	462	438	438	438	438	**383**
TE-21-5-3-5-3	572	686	586	547	686	586	547	547	547	547	**449**
TE-21-5-4-5-3	583	688	566	549	688	574	507	507	507	507	**463**
TE-21-5-5-5-3	664	658	690	697	658	657	662	662	662	662	**518**

Table A.59: Results for edge-disjointness on TE-21-5 instances.

	VND with									
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TE-21-5-1-3-1	0.07	0.04	0.04	0.04	0.02	0.02	0.02	0.02	0.02	0.02
TE-21-5-2-3-1	0.08	0.05	0.05	0.04	0.02	0.01	0.02	0.02	0.02	0.03
TE-21-5-3-3-1	0.06	0.03	0.03	0.04	0.02	0.01	0.02	0.01	0.02	0.02
TE-21-5-4-3-1	0.08	0.04	0.04	0.04	0.02	0.02	0.02	0.02	0.02	0.02
TE-21-5-5-3-1	0.07	0.04	0.04	0.04	0.01	0.01	0.01	0.01	0.01	0.01
TE-21-5-1-3-2	0.74	0.13	0.51	0.12	0.13	0.51	0.05	0.06	0.06	0.06
TE-21-5-2-3-2	0.47	0.12	0.36	0.08	0.09	0.31	0.03	0.03	0.03	0.02
TE-21-5-3-3-2	0.40	0.12	0.31	0.09	0.12	0.36	0.05	0.05	0.05	0.05
TE-21-5-4-3-2	0.74	0.15	0.49	0.10	0.14	0.39	0.04	0.05	0.05	0.05
TE-21-5-5-3-2	0.47	0.13	0.43	0.06	0.12	0.35	0.06	0.05	0.05	0.05
TE-21-5-1-3-3	0.87	0.15	0.62	0.18	0.14	0.60	0.07	0.07	0.06	0.05
TE-21-5-2-3-3	0.63	0.19	0.53	0.18	0.19	0.55	0.04	0.05	0.05	0.05
TE-21-5-3-3-3	0.54	0.20	0.43	0.19	0.21	0.45	0.09	0.09	0.09	0.08
TE-21-5-4-3-3	1.00	0.18	0.52	0.13	0.18	0.45	0.07	0.06	0.05	0.06
TE-21-5-5-3-3	0.58	0.13	0.59	0.16	0.14	0.46	0.09	0.09	0.09	0.09
TE-21-5-1-4-1	0.55	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.02	0.03
TE-21-5-2-4-1	0.49	0.06	0.05	0.05	0.04	0.03	0.03	0.03	0.04	0.04
TE-21-5-3-4-1	0.54	0.05	0.05	0.05	0.04	0.03	0.03	0.04	0.04	0.04
TE-21-5-4-4-1	0.51	0.04	0.04	0.04	0.02	0.02	0.02	0.02	0.02	0.02
TE-21-5-5-4-1	0.52	0.05	0.06	0.05	0.03	0.02	0.03	0.02	0.03	0.03
TE-21-5-1-4-2	1.18	0.66	0.96	0.13	0.67	0.82	0.02	0.03	0.03	0.03
TE-21-5-2-4-2	0.94	0.62	0.90	0.12	0.60	0.74	0.08	0.09	0.08	0.08
TE-21-5-3-4-2	0.79	0.70	0.71	0.10	0.71	0.72	0.06	0.05	0.06	0.06
TE-21-5-4-4-2	1.47	0.65	1.03	0.08	0.61	0.77	0.04	0.05	0.04	0.04
TE-21-5-5-4-2	0.85	0.64	0.85	0.12	0.63	0.78	0.03	0.02	0.03	0.03
TE-21-5-1-4-3	1.91	0.75	1.11	0.17	0.76	1.11	0.08	0.07	0.08	0.08
TE-21-5-2-4-3	1.10	0.72	1.04	0.23	0.76	1.02	0.11	0.12	0.12	0.12
TE-21-5-3-4-3	1.03	0.73	1.02	0.15	0.77	0.90	0.11	0.11	0.11	0.11
TE-21-5-4-4-3	2.52	0.91	1.13	0.15	0.88	0.85	0.09	0.09	0.10	0.10
TE-21-5-5-4-3	1.14	0.75	1.05	0.14	0.73	0.94	0.13	0.13	0.13	0.12
TE-21-5-1-5-1	8.20	0.07	0.06	0.06	0.03	0.03	0.04	0.04	0.04	0.04
TE-21-5-2-5-1	8.06	0.06	0.06	0.06	0.05	0.03	0.03	0.04	0.04	0.04
TE-21-5-3-5-1	8.01	0.06	0.06	0.06	0.05	0.03	0.04	0.04	0.04	0.04
TE-21-5-4-5-1	8.35	0.05	0.06	0.06	0.02	0.02	0.03	0.02	0.03	0.03
TE-21-5-5-5-1	8.00	0.06	0.06	0.05	0.03	0.03	0.03	0.03	0.03	0.03
TE-21-5-1-5-2	9.98	8.83	9.24	0.18	8.93	9.05	0.03	0.03	0.04	0.04
TE-21-5-2-5-2	9.47	9.02	9.14	0.14	9.02	9.05	0.14	0.14	0.15	0.15
TE-21-5-3-5-2	9.04	9.10	8.92	0.12	9.06	8.87	0.07	0.08	0.07	0.07
TE-21-5-4-5-2	11.14	8.90	9.50	0.12	8.73	8.98	0.07	0.06	0.06	0.06
TE-21-5-5-5-2	9.05	8.93	8.98	0.12	9.04	9.01	0.06	0.06	0.07	0.06
TE-21-5-1-5-3	14.22	9.27	10.29	0.22	9.37	9.85	0.10	0.10	0.11	0.10
TE-21-5-2-5-3	10.13	9.72	9.81	0.27	9.63	9.92	0.22	0.22	0.22	0.23
TE-21-5-3-5-3	10.24	9.64	9.97	0.16	9.60	9.59	0.13	0.13	0.13	0.12
TE-21-5-4-5-3	19.69	9.70	10.22	0.16	9.61	9.59	0.13	0.14	0.14	0.14
TE-21-5-5-5-3	10.20	9.62	9.99	0.18	9.77	9.91	0.15	0.15	0.15	0.16

Table A.60: Time consumation (s) for edge-disjointness on TE-21-5 instances.

	MSVND with												
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F		
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	**BOT**
TE-21-5-1-3-1	201.60	2.19	202.33	2.29	202.27	4.35	201.00	1.88	201.27	2.20	201.87	2.22	**200**
TE-21-5-2-3-1	157.13	0.51	157.07	0.37	157.33	0.76	157.20	0.61	157.40	0.81	157.27	0.69	**157**
TE-21-5-3-3-1	194.43	2.37	195.73	4.49	194.87	3.30	194.43	2.37	194.87	3.30	194.43	2.37	**193**
TE-21-5-4-3-1	187.27	5.31	189.07	6.37	185.17	4.60	187.37	5.39	186.87	5.05	187.77	5.67	**183**
TE-21-5-5-3-1	224.00	0.00	225.73	6.60	228.87	11.49	225.47	8.03	225.57	6.03	227.07	8.03	**224**
TE-21-5-1-3-2	388.00	0.00	388.00	0.00	388.00	0.00	386.07	13.64	387.67	12.62	381.57	8.46	**335**
TE-21-5-2-3-2	303.00	0.00	303.00	0.00	303.00	0.00	294.87	8.39	292.60	9.96	296.27	9.46	**267**
TE-21-5-3-3-2	349.00	0.00	349.00	0.00	349.00	0.00	360.60	6.73	360.00	6.19	359.00	5.23	**337**
TE-21-5-4-3-2	415.00	0.00	415.00	0.00	415.00	0.00	360.30	15.18	361.40	16.97	364.73	13.27	**330**
TE-21-5-5-3-2	519.00	0.00	519.00	0.00	519.00	0.00	416.33	11.78	418.80	14.26	418.17	10.97	**384**
TE-21-5-1-3-3	694.00	0.00	694.00	0.00	694.00	0.00	585.67	27.09	574.93	24.28	574.00	25.89	**479**
TE-21-5-2-3-3	441.00	0.00	441.00	0.00	441.00	0.00	406.33	15.95	408.77	18.66	410.57	19.02	**383**
TE-21-5-3-3-3	519.00	0.00	519.00	0.00	519.00	0.00	513.07	17.28	504.87	7.33	510.87	16.56	**449**
TE-21-5-4-3-3	631.00	0.00	631.00	0.00	631.00	0.00	524.47	16.85	523.03	19.00	518.17	16.83	**463**
TE-21-5-5-3-3	715.00	0.00	715.00	0.00	715.00	0.00	633.03	7.78	629.80	10.08	629.93	7.89	**526**
TE-21-5-1-4-1	200.73	0.98	200.53	0.90	200.73	0.98	201.00	1.46	200.60	1.07	200.67	0.96	**199**
TE-21-5-2-4-1	149.00	0.00	149.00	0.00	149.33	1.83	149.00	0.00	149.00	0.00	149.67	2.54	**149**
TE-21-5-3-4-1	191.40	2.19	191.00	0.00	191.00	0.00	191.00	0.00	191.40	2.19	191.00	0.00	**190**
TE-21-5-4-4-1	183.53	3.49	183.23	3.65	184.10	4.55	184.60	5.59	183.57	4.17	182.57	2.14	**180**
TE-21-5-5-4-1	220.00	4.62	219.00	0.00	219.17	0.91	219.83	4.56	219.00	0.00	220.53	5.86	**211**
TE-21-5-1-4-2	470.00	0.00	470.00	0.00	470.00	0.00	398.13	20.00	405.67	19.37	400.67	18.58	**328**
TE-21-5-2-4-2	272.00	0.00	272.00	0.00	272.00	0.00	296.43	10.23	296.93	10.67	293.83	9.96	**257**
TE-21-5-3-4-2	518.00	0.00	518.00	0.00	518.00	0.00	352.17	13.85	357.50	16.50	359.57	13.64	**287**
TE-21-5-4-4-2	470.00	0.00	470.00	0.00	470.00	0.00	339.87	15.40	355.50	17.87	345.73	17.55	**305**
TE-21-5-5-4-2	524.00	0.00	524.00	0.00	524.00	0.00	402.60	16.01	405.67	20.49	406.63	16.42	**353**
TE-21-5-1-4-3	580.00	0.00	580.00	0.00	580.00	0.00	581.80	7.64	581.47	8.27	583.13	9.28	**476**
TE-21-5-2-4-3	459.00	0.00	459.00	0.00	459.00	0.00	408.43	25.05	402.60	29.17	414.17	30.99	**383**
TE-21-5-3-4-3	673.00	0.00	673.00	0.00	673.00	0.00	496.07	27.18	507.53	26.78	492.53	26.35	**449**
TE-21-5-4-4-3	554.00	0.00	554.00	0.00	554.00	0.00	530.07	7.83	530.63	6.35	531.80	6.01	**463**
TE-21-5-5-4-3	743.00	0.00	743.00	0.00	743.00	0.00	596.57	24.95	599.23	23.80	603.70	31.06	**525**
TE-21-5-1-5-1	200.93	1.01	200.67	0.96	200.40	0.81	200.47	0.86	200.80	1.00	200.87	1.01	**199**
TE-21-5-2-5-1	149.00	0.00	149.00	0.00	149.00	0.00	149.00	0.00	149.00	0.00	149.00	0.00	**149**
TE-21-5-3-5-1	191.40	2.19	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00	**189**
TE-21-5-4-5-1	182.97	3.10	184.77	7.25	182.67	3.10	183.40	4.33	183.80	4.89	184.83	6.64	**180**
TE-21-5-5-5-1	216.10	0.55	216.00	0.00	216.00	0.00	216.00	0.00	216.00	0.00	216.00	0.00	**211**
TE-21-5-1-5-2	390.00	0.00	390.00	0.00	390.00	0.00	361.60	11.05	356.67	10.39	364.20	12.25	**288**
TE-21-5-2-5-2	226.00	0.00	226.00	0.00	226.00	0.00	280.67	10.55	278.67	10.70	281.07	9.62	**226**
TE-21-5-3-5-2	344.00	0.00	344.00	0.00	344.00	0.00	322.43	20.47	320.17	19.36	315.97	16.24	**267**
TE-21-5-4-5-2	448.00	0.00	448.00	0.00	448.00	0.00	343.40	8.45	344.03	10.69	343.67	8.20	**285**
TE-21-5-5-5-2	462.00	0.00	462.00	0.00	462.00	0.00	372.23	27.87	364.30	27.10	365.37	25.35	**308**
TE-21-5-1-5-3	580.00	0.00	580.00	0.00	580.00	0.00	564.27	20.98	558.53	19.64	565.40	17.80	**475**
TE-21-5-2-5-3	436.00	0.00	436.00	0.00	436.00	0.00	401.70	17.28	402.53	21.37	400.33	17.36	**383**
TE-21-5-3-5-3	686.00	0.00	686.00	0.00	686.00	0.00	491.40	20.23	488.97	19.19	488.07	16.94	**449**
TE-21-5-4-5-3	688.00	0.00	688.00	0.00	688.00	0.00	509.53	12.32	507.60	10.02	507.43	10.46	**463**
TE-21-5-5-5-3	658.00	0.00	658.00	0.00	658.00	0.00	572.70	26.19	578.77	25.86	574.40	22.27	**518**

Table A.61: Results for edge-disjointness on TE-21-5 instances.

	MSVND with											
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TE-21-5-1-3-1	0.20	0.02	0.20	0.02	0.20	0.02	0.20	0.02	0.20	0.02	0.20	0.02
TE-21-5-2-3-1	0.21	0.02	0.21	0.02	0.21	0.02	0.21	0.02	0.21	0.02	0.21	0.02
TE-21-5-3-3-1	0.22	0.02	0.22	0.02	0.21	0.02	0.22	0.02	0.22	0.02	0.22	0.02
TE-21-5-4-3-1	0.17	0.01	0.16	0.01	0.17	0.01	0.17	0.01	0.17	0.01	0.16	0.01
TE-21-5-5-3-1	0.19	0.02	0.18	0.02	0.18	0.01	0.19	0.02	0.18	0.01	0.19	0.02
TE-21-5-1-3-2	1.21	0.02	1.21	0.02	1.21	0.02	0.46	0.05	0.47	0.04	0.48	0.03
TE-21-5-2-3-2	1.04	0.02	1.04	0.02	1.04	0.02	0.49	0.05	0.49	0.04	0.49	0.04
TE-21-5-3-3-2	1.04	0.01	1.04	0.02	1.04	0.02	0.57	0.04	0.58	0.05	0.58	0.05
TE-21-5-4-3-2	1.37	0.02	1.38	0.02	1.37	0.01	0.46	0.04	0.45	0.04	0.46	0.05
TE-21-5-5-3-2	1.23	0.02	1.22	0.02	1.23	0.02	0.45	0.04	0.44	0.03	0.44	0.03
TE-21-5-1-3-3	1.30	0.02	1.31	0.02	1.30	0.02	0.77	0.06	0.78	0.07	0.76	0.07
TE-21-5-2-3-3	1.66	0.02	1.66	0.02	1.66	0.02	0.82	0.06	0.80	0.06	0.82	0.06
TE-21-5-3-3-3	1.90	0.02	1.93	0.15	1.90	0.02	0.88	0.07	0.91	0.07	0.90	0.07
TE-21-5-4-3-3	1.61	0.02	1.61	0.02	1.62	0.02	0.78	0.05	0.77	0.06	0.77	0.06
TE-21-5-5-3-3	1.24	0.02	1.24	0.02	1.23	0.02	0.79	0.06	0.82	0.06	0.82	0.06
TE-21-5-1-4-1	0.25	0.03	0.25	0.02	0.25	0.03	0.25	0.02	0.25	0.03	0.24	0.02
TE-21-5-2-4-1	0.30	0.02	0.29	0.03	0.29	0.02	0.29	0.02	0.28	0.03	0.29	0.02
TE-21-5-3-4-1	0.29	0.03	0.30	0.03	0.29	0.02	0.29	0.03	0.30	0.02	0.29	0.02
TE-21-5-4-4-1	0.22	0.02	0.22	0.02	0.22	0.02	0.21	0.02	0.21	0.02	0.22	0.02
TE-21-5-5-4-1	0.26	0.02	0.27	0.02	0.26	0.02	0.26	0.02	0.26	0.02	0.25	0.02
TE-21-5-1-4-2	5.68	0.06	5.69	0.07	5.67	0.08	0.38	0.05	0.38	0.05	0.38	0.05
TE-21-5-2-4-2	5.70	0.08	5.67	0.07	5.71	0.06	0.58	0.05	0.56	0.06	0.56	0.06
TE-21-5-3-4-2	6.40	0.08	6.44	0.07	6.42	0.07	0.61	0.06	0.61	0.06	0.61	0.05
TE-21-5-4-4-2	5.80	0.08	5.80	0.08	5.78	0.07	0.51	0.07	0.46	0.05	0.48	0.07
TE-21-5-5-4-2	5.42	0.07	5.47	0.07	5.47	0.07	0.57	0.07	0.54	0.07	0.57	0.07
TE-21-5-1-4-3	6.73	0.08	6.71	0.08	6.70	0.08	0.90	0.10	0.92	0.09	0.85	0.10
TE-21-5-2-4-3	6.70	0.07	6.71	0.06	6.68	0.09	0.97	0.11	1.00	0.11	0.96	0.13
TE-21-5-3-4-3	6.74	0.07	6.76	0.08	6.74	0.07	1.20	0.12	1.15	0.09	1.20	0.12
TE-21-5-4-4-3	7.84	0.07	7.81	0.07	7.82	0.09	1.01	0.12	1.04	0.10	0.98	0.11
TE-21-5-5-4-3	6.46	0.06	6.46	0.07	6.46	0.07	1.00	0.11	0.99	0.07	0.97	0.11
TE-21-5-1-5-1	0.30	0.04	0.29	0.03	0.29	0.03	0.29	0.04	0.30	0.03	0.29	0.03
TE-21-5-2-5-1	0.33	0.03	0.34	0.02	0.33	0.03	0.34	0.02	0.33	0.02	0.33	0.02
TE-21-5-3-5-1	0.34	0.03	0.33	0.03	0.33	0.03	0.34	0.02	0.34	0.03	0.34	0.02
TE-21-5-4-5-1	0.25	0.02	0.25	0.02	0.26	0.03	0.26	0.02	0.26	0.02	0.26	0.02
TE-21-5-5-5-1	0.32	0.02	0.33	0.02	0.32	0.02	0.32	0.03	0.31	0.02	0.31	0.03
TE-21-5-1-5-2	79.19	0.32	79.37	0.33	79.24	0.30	0.79	0.11	0.78	0.11	0.77	0.12
TE-21-5-2-5-2	80.49	1.40	86.96	13.28	80.44	0.27	0.82	0.07	0.83	0.07	0.83	0.07
TE-21-5-3-5-2	83.33	7.64	82.34	6.35	80.36	0.30	0.87	0.08	0.82	0.09	0.85	0.07
TE-21-5-4-5-2	79.05	0.31	79.10	0.33	79.12	0.21	0.64	0.05	0.64	0.07	0.65	0.06
TE-21-5-5-5-2	79.94	0.29	86.37	9.39	83.63	6.57	0.77	0.06	0.78	0.07	0.77	0.06
TE-21-5-1-5-3	84.91	0.26	85.07	0.34	85.02	0.32	1.20	0.18	1.23	0.14	1.22	0.12
TE-21-5-2-5-3	87.44	4.63	102.85	21.22	92.85	13.76	1.39	0.13	1.40	0.15	1.39	0.13
TE-21-5-3-5-3	86.15	0.27	86.19	0.27	86.10	0.35	1.57	0.19	1.54	0.19	1.57	0.20
TE-21-5-4-5-3	86.30	0.31	86.36	0.34	86.36	0.32	1.28	0.19	1.31	0.17	1.27	0.12
TE-21-5-5-5-3	86.60	0.35	86.52	0.31	86.62	0.40	1.27	0.13	1.26	0.14	1.36	0.15

Table A.62: Time consumation (s) for edge-disjointness on TE-21-5 instances.

	GRASP												
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$		
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	**BOT**
TE-21-5-1-3-1	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	**200**
TE-21-5-2-3-1	159.00	0.00	159.00	0.00	159.00	0.00	159.00	0.00	159.00	0.00	159.00	0.00	**157**
TE-21-5-3-3-1	217.00	0.00	217.00	0.00	217.00	0.00	217.00	0.00	217.00	0.00	217.00	0.00	**193**
TE-21-5-4-3-1	216.00	0.00	216.00	0.00	216.00	0.00	216.00	0.00	216.00	0.00	216.00	0.00	**183**
TE-21-5-5-3-1	224.00	0.00	224.00	0.00	224.00	0.00	224.00	0.00	224.00	0.00	224.00	0.00	**224**
TE-21-5-1-3-2	485.87	2.03	434.73	25.43	436.87	29.16	441.97	37.12	492.43	69.12	481.27	47.89	**335**
TE-21-5-2-3-2	319.00	0.00	322.57	20.73	339.67	35.24	362.60	45.67	372.57	56.20	391.97	43.85	**267**
TE-21-5-3-3-2	385.00	0.00	398.77	16.60	405.43	23.78	417.40	37.04	446.20	66.08	452.83	89.98	**337**
TE-21-5-4-3-2	379.70	13.49	392.13	23.45	382.60	28.49	409.43	46.47	442.10	59.11	420.67	39.53	**330**
TE-21-5-5-3-2	488.07	28.49	500.17	16.88	504.57	24.86	507.27	33.58	508.23	37.81	510.80	58.11	**384**
TE-21-5-1-3-3	684.13	39.69	670.60	41.18	651.30	25.02	645.80	42.73	667.13	69.49	701.93	78.84	**479**
TE-21-5-2-3-3	507.97	30.38	500.13	28.54	515.67	35.25	530.47	60.36	561.73	68.42	564.93	89.45	**383**
TE-21-5-3-3-3	591.33	11.62	612.13	26.67	594.93	34.74	599.40	43.70	622.67	77.55	640.00	90.53	**449**
TE-21-5-4-3-3	577.93	25.07	584.03	35.37	584.57	35.18	599.23	48.33	642.37	71.86	633.27	64.86	**463**
TE-21-5-5-3-3	758.33	5.22	759.97	22.06	750.17	34.84	744.10	54.31	740.33	65.59	726.67	76.98	**526**
TE-21-5-1-4-1	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	**199**
TE-21-5-2-4-1	159.00	0.00	159.00	0.00	159.00	0.00	159.00	0.00	159.00	0.00	159.00	0.00	**149**
TE-21-5-3-4-1	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00	**190**
TE-21-5-4-4-1	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	**180**
TE-21-5-5-4-1	219.00	0.00	219.00	0.00	219.00	0.00	219.00	0.00	219.00	0.00	219.00	0.00	**211**
TE-21-5-1-4-2	397.60	10.46	408.27	19.11	431.13	36.26	442.07	61.95	457.90	72.28	475.90	75.88	**328**
TE-21-5-2-4-2	309.00	0.00	320.63	20.41	337.97	44.36	353.10	46.38	379.60	77.22	394.73	84.16	**257**
TE-21-5-3-4-2	381.00	0.00	389.77	12.99	395.30	36.36	403.10	53.22	458.47	84.70	444.57	86.13	**287**
TE-21-5-4-4-2	367.97	27.19	375.83	28.40	392.60	30.85	397.77	42.10	423.13	68.63	403.40	49.83	**305**
TE-21-5-5-4-2	450.87	2.03	454.17	23.02	458.07	33.96	470.97	51.72	456.00	39.66	490.20	80.11	**353**
TE-21-5-1-4-3	611.57	11.27	605.73	28.65	619.37	43.95	626.17	58.00	655.57	101.28	675.10	105.51	**476**
TE-21-5-2-4-3	507.00	0.00	488.97	38.94	496.03	55.23	514.67	95.12	552.97	110.96	554.17	93.35	**383**
TE-21-5-3-4-3	591.87	8.38	586.47	30.86	559.40	38.86	591.70	59.50	649.47	110.27	640.03	116.34	**449**
TE-21-5-4-4-3	556.37	24.89	565.40	38.50	571.73	52.59	589.97	62.15	618.90	78.56	625.40	86.36	**463**
TE-21-5-5-4-3	708.03	19.38	689.40	22.38	674.10	55.12	706.63	77.41	727.80	80.11	725.70	80.58	**525**
TE-21-5-1-5-1	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	**199**
TE-21-5-2-5-1	159.00	0.00	159.00	0.00	159.00	0.00	159.00	0.00	159.00	0.00	159.00	0.00	**149**
TE-21-5-3-5-1	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00	191.00	0.00	**189**
TE-21-5-4-5-1	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	200.00	0.00	**180**
TE-21-5-5-5-1	219.00	0.00	219.00	0.00	219.00	0.00	219.00	0.00	219.00	0.00	219.00	0.00	**211**
TE-21-5-1-5-2	359.00	0.00	376.50	14.86	413.97	39.88	424.33	54.70	415.13	61.97	457.97	84.72	**288**
TE-21-5-2-5-2	314.50	14.75	309.83	13.21	332.87	45.02	346.77	69.19	355.30	89.07	369.93	90.83	**226**
TE-21-5-3-5-2	379.40	10.73	376.57	15.79	369.17	36.89	385.67	53.67	436.37	83.54	436.17	96.65	**267**
TE-21-5-4-5-2	361.37	18.36	371.03	28.95	379.63	26.82	391.43	64.43	397.73	78.40	397.07	71.04	**285**
TE-21-5-5-5-2	423.23	9.45	424.60	20.71	441.33	39.13	455.33	51.86	466.07	55.76	497.13	71.42	**308**
TE-21-5-1-5-3	563.00	0.00	582.80	29.06	618.43	42.29	622.30	73.92	678.10	86.25	665.83	110.42	**475**
TE-21-5-2-5-3	467.87	5.58	457.17	22.66	498.83	63.45	536.13	98.20	520.60	78.61	547.37	94.23	**383**
TE-21-5-3-5-3	560.83	11.71	566.07	26.26	554.50	51.27	628.10	64.60	658.13	88.05	630.57	92.17	**449**
TE-21-5-4-5-3	542.17	15.88	549.03	28.92	587.03	62.78	595.83	83.58	605.13	93.63	600.37	80.17	**463**
TE-21-5-5-5-3	678.93	8.64	672.70	26.24	667.00	45.79	665.43	62.00	703.90	76.68	752.93	93.59	**518**

Table A.63: Results for edge-disjointness on TE-21-5 instances.

	GRASP											
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TE-21-5-1-3-1	0.08	0.01	0.08	0.01	0.08	0.01	0.08	0.01	0.08	0.01	0.08	0.01
TE-21-5-2-3-1	0.08	0.01	0.08	0.01	0.08	0.01	0.08	0.01	0.08	0.01	0.08	0.01
TE-21-5-3-3-1	0.06	0.01	0.06	0.01	0.07	0.01	0.06	0.01	0.06	0.01	0.06	0.01
TE-21-5-4-3-1	0.07	0.01	0.07	0.01	0.07	0.01	0.07	0.01	0.07	0.01	0.07	0.01
TE-21-5-5-3-1	0.08	0.01	0.08	0.01	0.08	0.01	0.07	0.01	0.08	0.01	0.07	0.01
TE-21-5-1-3-2	0.70	0.01	0.68	0.06	0.47	0.08	0.31	0.11	0.28	0.05	0.27	0.04
TE-21-5-2-3-2	0.47	0.02	0.47	0.08	0.36	0.11	0.28	0.06	0.27	0.07	0.26	0.06
TE-21-5-3-3-2	0.40	0.03	0.36	0.05	0.32	0.09	0.29	0.07	0.28	0.07	0.27	0.05
TE-21-5-4-3-2	0.73	0.02	0.70	0.11	0.43	0.17	0.28	0.07	0.28	0.06	0.26	0.05
TE-21-5-5-3-2	0.44	0.03	0.42	0.04	0.34	0.06	0.34	0.10	0.29	0.06	0.25	0.06
TE-21-5-1-3-3	0.84	0.02	0.85	0.09	0.64	0.12	0.46	0.11	0.45	0.12	0.41	0.09
TE-21-5-2-3-3	0.64	0.04	0.64	0.11	0.57	0.15	0.43	0.11	0.43	0.09	0.40	0.08
TE-21-5-3-3-3	0.56	0.03	0.51	0.07	0.48	0.11	0.46	0.16	0.40	0.10	0.43	0.12
TE-21-5-4-3-3	0.97	0.03	0.98	0.10	0.74	0.17	0.44	0.11	0.42	0.08	0.41	0.11
TE-21-5-5-3-3	0.56	0.03	0.56	0.05	0.48	0.06	0.48	0.11	0.40	0.08	0.43	0.09
TE-21-5-1-4-1	0.53	0.02	0.53	0.02	0.52	0.02	0.53	0.02	0.54	0.02	0.53	0.03
TE-21-5-2-4-1	0.54	0.02	0.53	0.03	0.53	0.02	0.53	0.03	0.53	0.02	0.54	0.02
TE-21-5-3-4-1	0.55	0.02	0.55	0.03	0.54	0.02	0.54	0.02	0.55	0.03	0.54	0.03
TE-21-5-4-4-1	0.53	0.02	0.53	0.03	0.53	0.03	0.53	0.02	0.53	0.02	0.53	0.02
TE-21-5-5-4-1	0.53	0.03	0.54	0.02	0.52	0.03	0.53	0.02	0.54	0.02	0.54	0.02
TE-21-5-1-4-2	1.18	0.04	1.16	0.15	0.99	0.22	0.81	0.09	0.75	0.09	0.79	0.10
TE-21-5-2-4-2	0.93	0.03	0.90	0.08	0.91	0.17	0.80	0.11	0.78	0.15	0.78	0.07
TE-21-5-3-4-2	0.77	0.03	0.80	0.05	0.78	0.09	0.77	0.07	0.80	0.14	0.79	0.09
TE-21-5-4-4-2	1.54	0.09	1.70	0.37	1.12	0.31	0.79	0.08	0.81	0.11	0.79	0.07
TE-21-5-5-4-2	0.82	0.02	0.84	0.05	0.80	0.08	0.84	0.10	0.80	0.08	0.76	0.06
TE-21-5-1-4-3	1.76	0.06	1.55	0.16	1.47	0.27	1.11	0.27	1.07	0.20	1.07	0.20
TE-21-5-2-4-3	1.08	0.04	1.14	0.13	1.37	0.40	1.07	0.22	1.00	0.16	1.02	0.19
TE-21-5-3-4-3	1.00	0.06	1.02	0.07	1.03	0.15	1.09	0.22	1.01	0.16	0.98	0.14
TE-21-5-4-4-3	2.46	0.10	2.48	0.47	1.94	0.61	1.12	0.24	0.97	0.11	1.00	0.14
TE-21-5-5-4-3	1.03	0.05	1.11	0.10	1.08	0.13	1.13	0.19	1.03	0.14	1.04	0.16
TE-21-5-1-5-1	8.20	0.11	8.20	0.10	8.23	0.12	8.20	0.11	8.21	0.10	8.20	0.07
TE-21-5-2-5-1	8.21	0.09	8.23	0.11	8.20	0.08	8.21	0.12	8.19	0.08	8.21	0.10
TE-21-5-3-5-1	8.21	0.09	8.19	0.10	8.20	0.08	8.19	0.10	8.21	0.11	8.76	1.34
TE-21-5-4-5-1	8.21	0.09	8.22	0.10	8.18	0.10	8.18	0.10	8.21	0.13	8.23	0.12
TE-21-5-5-5-1	8.27	0.08	8.28	0.11	8.26	0.08	8.27	0.10	8.24	0.09	8.26	0.09
TE-21-5-1-5-2	9.88	0.12	9.98	0.37	9.54	0.48	9.15	0.24	9.05	0.17	9.08	0.22
TE-21-5-2-5-2	9.65	1.27	10.58	2.20	10.63	2.19	9.15	0.16	9.25	0.24	9.21	0.17
TE-21-5-3-5-2	9.11	0.09	9.28	0.58	10.46	1.60	9.14	0.17	9.12	0.18	9.16	0.37
TE-21-5-4-5-2	11.56	0.68	12.52	2.41	9.71	0.74	9.12	0.42	9.06	0.17	9.09	0.19
TE-21-5-5-5-2	9.16	0.12	11.10	2.53	9.17	0.16	9.09	0.14	9.05	0.17	9.10	0.23
TE-21-5-1-5-3	13.66	0.29	12.75	2.07	11.87	2.05	10.25	0.63	10.06	0.24	9.95	0.27
TE-21-5-2-5-3	9.96	0.10	10.65	0.89	11.36	1.74	10.18	0.36	10.07	0.39	10.24	0.48
TE-21-5-3-5-3	9.97	0.16	9.94	0.22	10.16	0.50	10.03	0.37	9.99	0.26	9.96	0.28
TE-21-5-4-5-3	18.67	0.84	19.03	4.16	12.16	2.17	10.22	0.72	10.09	0.49	10.03	0.34
TE-21-5-5-5-3	10.12	0.16	10.14	0.34	10.12	0.38	10.18	0.48	10.06	0.42	10.08	0.90

Table A.64: Time consumation (s) for edge-disjointness on TE-21-5 instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F	**BOT**
TE-21-10-1-3-1	787	787	787	787	359	359	359	359	359	359	**306**
TE-21-10-2-3-1	634	634	634	634	339	339	339	339	339	339	**281**
TE-21-10-3-3-1	662	662	662	662	424	424	424	424	424	424	**296**
TE-21-10-4-3-1	683	683	683	683	327	327	327	327	327	327	**266**
TE-21-10-5-3-1	606	606	606	606	292	292	292	292	292	292	**257**
TE-21-10-1-3-2	786	1789	954	1294	1789	958	724	724	724	724	**547**
TE-21-10-2-3-2	697	1787	1052	1202	1787	850	755	755	755	755	**520**
TE-21-10-3-3-2	637	1897	865	1143	1897	747	775	775	775	775	**515**
TE-21-10-4-3-2	676	2030	939	1119	2030	834	730	730	730	730	**473**
TE-21-10-5-3-2	588	1643	802	1065	1643	620	624	624	624	624	**432**
TE-21-10-1-3-3	1075	2178	1479	1785	2178	1095	1187	1187	1187	1187	**761**
TE-21-10-2-3-3	1011	2126	1435	1701	2126	1250	1091	1091	1091	1091	**721**
TE-21-10-3-3-3	931	2474	1238	1579	2474	1090	1123	1123	1123	1123	**743**
TE-21-10-4-3-3	941	2539	1288	1511	2539	1109	1124	1124	1124	1124	**653**
TE-21-10-5-3-3	896	2053	1080	1500	2053	914	1023	1023	1023	1023	**627**
TE-21-10-1-4-1	787	787	787	787	298	298	298	298	298	298	**282**
TE-21-10-2-4-1	634	634	634	634	309	309	309	309	309	309	**271**
TE-21-10-3-4-1	662	662	662	662	372	372	372	372	372	372	**272**
TE-21-10-4-4-1	683	683	683	683	315	315	315	315	315	315	**251**
TE-21-10-5-4-1	606	606	606	606	292	292	292	292	292	292	**230**
TE-21-10-1-4-2	635	1788	893	1294	1788	729	682	682	682	682	**458**
TE-21-10-2-4-2	638	1657	839	1202	1657	749	637	637	637	637	**457**
TE-21-10-3-4-2	600	1968	775	1143	1968	602	705	705	705	705	**462**
TE-21-10-4-4-2	560	1957	694	1119	1957	604	654	654	654	654	**417**
TE-21-10-5-4-2	475	1658	613	1065	1658	475	581	581	581	581	**371**
TE-21-10-1-4-3	890	2301	1200	1785	2301	1050	1089	1089	1089	1089	**654**
TE-21-10-2-4-3	883	2141	1175	1701	2141	1063	931	931	931	931	**636**
TE-21-10-3-4-3	873	2356	1162	1579	2356	935	1051	1051	1051	1051	**663**
TE-21-10-4-4-3	782	2645	947	1511	2645	944	908	908	908	908	**576**
TE-21-10-5-4-3	673	2052	847	1500	2052	687	905	905	905	905	**549**
TE-21-10-1-5-1	787	787	787	787	287	287	287	287	287	287	**269**
TE-21-10-2-5-1	634	634	634	634	303	303	303	303	303	303	**258**
TE-21-10-3-5-1	662	662	662	662	372	372	372	372	372	372	**272**
TE-21-10-4-5-1	683	683	683	683	309	309	309	309	309	309	**238**
TE-21-10-5-5-1	606	606	606	606	292	292	292	292	292	292	**216**
TE-21-10-1-5-2	554	1928	702	1294	1928	674	654	654	654	654	**424**
TE-21-10-2-5-2	588	1753	698	1202	1753	616	637	637	637	637	**423**
TE-21-10-3-5-2	582	1933	721	1143	1933	594	640	640	640	640	**423**
TE-21-10-4-5-2	550	2141	656	1119	2141	636	619	619	619	619	**377**
TE-21-10-5-5-2	475	1676	502	1065	1676	475	581	581	581	581	**346**
TE-21-10-1-5-3	880	2476	1078	1785	2476	988	1022	1022	1022	1022	**622**
TE-21-10-2-5-3	806	2352	1032	1701	2352	914	931	931	931	931	**580**
TE-21-10-3-5-3	787	2516	949	1579	2516	825	981	981	981	981	**625**
TE-21-10-4-5-3	757	2925	835	1511	2925	795	875	875	875	875	**540**
TE-21-10-5-5-3	653	2143	773	1500	2143	721	905	905	905	905	**519**

Table A.65: Results for edge-disjointness on TE-21-10 instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TE-21-10-1-3-1	0.06	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.00
TE-21-10-2-3-1	0.08	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.01
TE-21-10-3-3-1	0.06	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.00
TE-21-10-4-3-1	0.06	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.00
TE-21-10-5-3-1	0.08	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.01
TE-21-10-1-3-2	1.28	0.07	0.84	0.02	0.09	0.90	0.01	0.02	0.02	0.01
TE-21-10-2-3-2	0.96	0.07	0.65	0.01	0.08	0.57	0.02	0.01	0.01	0.01
TE-21-10-3-3-2	0.75	0.08	0.48	0.00	0.07	0.46	0.01	0.02	0.02	0.02
TE-21-10-4-3-2	1.24	0.08	0.90	0.01	0.07	0.64	0.01	0.01	0.01	0.02
TE-21-10-5-3-2	0.66	0.06	0.54	0.01	0.08	0.37	0.00	0.01	0.01	0.01
TE-21-10-1-3-3	1.58	0.08	1.03	0.01	0.06	0.95	0.02	0.02	0.02	0.02
TE-21-10-2-3-3	1.13	0.07	0.86	0.02	0.07	0.71	0.02	0.01	0.02	0.02
TE-21-10-3-3-3	0.86	0.08	0.66	0.02	0.07	0.58	0.02	0.02	0.01	0.02
TE-21-10-4-3-3	1.36	0.09	1.01	0.02	0.08	0.73	0.02	0.01	0.02	0.02
TE-21-10-5-3-3	0.85	0.08	0.65	0.02	0.09	0.57	0.02	0.02	0.02	0.01
TE-21-10-1-4-1	1.00	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.02
TE-21-10-2-4-1	1.00	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01
TE-21-10-3-4-1	0.97	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01
TE-21-10-4-4-1	0.98	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.02	0.01
TE-21-10-5-4-1	0.98	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01
TE-21-10-1-4-2	2.05	1.08	1.60	0.01	0.96	1.46	0.02	0.02	0.02	0.01
TE-21-10-2-4-2	1.85	1.05	1.36	0.02	1.05	1.41	0.02	0.02	0.02	0.02
TE-21-10-3-4-2	1.50	0.98	1.35	0.01	1.00	1.36	0.02	0.01	0.01	0.01
TE-21-10-4-4-2	2.70	0.99	1.80	0.02	1.04	1.52	0.01	0.02	0.02	0.02
TE-21-10-5-4-2	1.48	1.06	1.30	0.01	1.09	1.26	0.01	0.01	0.02	0.02
TE-21-10-1-4-3	3.54	1.12	1.81	0.02	1.16	1.76	0.02	0.03	0.03	0.02
TE-21-10-2-4-3	2.17	1.03	1.72	0.03	1.14	1.64	0.03	0.01	0.02	0.02
TE-21-10-3-4-3	1.79	1.06	1.54	0.02	1.06	1.54	0.03	0.02	0.03	0.02
TE-21-10-4-4-3	3.05	1.12	2.13	0.02	1.12	1.71	0.02	0.03	0.03	0.02
TE-21-10-5-4-3	1.71	1.07	1.62	0.03	1.08	1.40	0.03	0.02	0.02	0.02
TE-21-10-1-5-1	16.36	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01
TE-21-10-2-5-1	16.31	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02
TE-21-10-3-5-1	16.11	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02
TE-21-10-4-5-1	16.23	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01
TE-21-10-5-5-1	16.26	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
TE-21-10-1-5-2	19.87	17.65	18.25	0.03	17.33	18.19	0.02	0.02	0.02	0.03
TE-21-10-2-5-2	18.08	17.18	17.85	0.02	17.30	17.43	0.02	0.02	0.01	0.02
TE-21-10-3-5-2	18.65	17.49	18.08	0.02	17.55	18.00	0.02	0.01	0.01	0.01
TE-21-10-4-5-2	22.39	17.55	18.84	0.02	17.39	18.01	0.02	0.03	0.02	0.01
TE-21-10-5-5-2	18.03	17.64	17.99	0.02	17.66	17.55	0.02	0.02	0.02	0.02
TE-21-10-1-5-3	30.77	18.19	19.62	0.02	18.41	19.38	0.03	0.03	0.03	0.03
TE-21-10-2-5-3	19.99	18.56	19.17	0.03	18.71	18.95	0.04	0.02	0.02	0.03
TE-21-10-3-5-3	19.66	18.48	18.97	0.03	18.56	19.03	0.03	0.02	0.03	0.03
TE-21-10-4-5-3	25.73	18.34	20.39	0.02	18.71	19.13	0.03	0.03	0.03	0.03
TE-21-10-5-5-3	19.04	18.64	19.12	0.03	18.16	19.02	0.02	0.03	0.03	0.03

Table A.66: Time consumation (s) for edge-disjointness on TE-21-10 instances.

	VND with										
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F	**BOT**
TE-21-10-1-3-1	338	338	338	338	352	352	352	352	352	352	**306**
TE-21-10-2-3-1	340	340	340	340	339	339	339	339	339	339	**281**
TE-21-10-3-3-1	317	317	317	317	372	372	372	372	372	372	**296**
TE-21-10-4-3-1	308	308	308	308	327	327	327	327	327	327	**266**
TE-21-10-5-3-1	269	269	269	269	292	292	292	292	292	292	**257**
TE-21-10-1-3-2	786	651	834	598	651	824	665	665	665	665	**547**
TE-21-10-2-3-2	697	626	691	555	626	770	652	652	652	652	**520**
TE-21-10-3-3-2	637	842	683	591	842	663	579	579	579	579	**515**
TE-21-10-4-3-2	676	710	708	554	710	679	650	650	650	650	**473**
TE-21-10-5-3-2	562	505	593	462	505	604	533	533	533	533	**432**
TE-21-10-1-3-3	1058	1035	1006	869	1035	1069	1063	1063	1063	1063	**761**
TE-21-10-2-3-3	971	976	1071	888	976	981	977	977	977	977	**721**
TE-21-10-3-3-3	921	1258	999	959	1258	937	908	908	908	908	**743**
TE-21-10-4-3-3	925	918	949	717	918	965	817	817	817	817	**653**
TE-21-10-5-3-3	896	848	875	734	848	896	745	745	745	745	**627**
TE-21-10-1-4-1	285	285	285	285	298	298	298	298	298	298	**282**
TE-21-10-2-4-1	283	283	283	283	309	309	309	309	309	309	**271**
TE-21-10-3-4-1	284	284	284	284	319	319	319	319	319	319	**272**
TE-21-10-4-4-1	271	271	271	271	315	315	315	315	315	315	**251**
TE-21-10-5-4-1	244	244	244	244	263	263	263	263	263	263	**230**
TE-21-10-1-4-2	631	662	636	522	662	691	544	544	544	544	**458**
TE-21-10-2-4-2	612	574	629	554	574	630	571	571	571	571	**457**
TE-21-10-3-4-2	583	625	612	562	625	583	631	631	631	631	**462**
TE-21-10-4-4-2	560	639	608	479	639	568	610	610	610	610	**417**
TE-21-10-5-4-2	458	455	567	500	455	470	450	450	450	450	**371**
TE-21-10-1-4-3	858	874	1012	788	874	939	881	881	881	881	**654**
TE-21-10-2-4-3	869	891	969	862	891	898	836	836	836	836	**636**
TE-21-10-3-4-3	847	1012	926	781	1012	924	904	904	904	904	**663**
TE-21-10-4-4-3	770	813	861	717	813	860	849	849	849	849	**576**
TE-21-10-5-4-3	665	915	784	686	915	668	823	823	823	823	**549**
TE-21-10-1-5-1	271	271	271	271	287	287	287	287	287	287	**269**
TE-21-10-2-5-1	280	280	280	280	303	303	303	303	303	303	**258**
TE-21-10-3-5-1	280	280	280	280	299	299	299	299	299	299	**272**
TE-21-10-4-5-1	271	271	271	271	307	307	307	307	307	307	**238**
TE-21-10-5-5-1	222	222	222	222	249	249	249	249	249	249	**216**
TE-21-10-1-5-2	538	528	596	523	528	625	556	556	556	556	**424**
TE-21-10-2-5-2	566	513	587	526	513	577	535	535	535	535	**423**
TE-21-10-3-5-2	564	1016	588	499	1016	525	534	534	534	534	**423**
TE-21-10-4-5-2	540	541	533	447	541	521	569	569	569	569	**377**
TE-21-10-5-5-2	442	557	476	455	557	442	412	412	412	412	**346**
TE-21-10-1-5-3	880	916	881	806	916	870	875	875	875	875	**622**
TE-21-10-2-5-3	778	854	869	849	854	845	820	820	820	820	**580**
TE-21-10-3-5-3	750	946	768	741	946	808	716	716	716	716	**625**
TE-21-10-4-5-3	745	737	762	696	737	783	795	795	795	795	**540**
TE-21-10-5-5-3	636	789	717	677	789	606	683	683	683	683	**519**

Table A.67: Results for edge-disjointness on TE-21-10 instances.

	VND with									
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
TE-21-10-1-3-1	0.22	0.14	0.15	0.14	0.06	0.07	0.06	0.06	0.07	0.06
TE-21-10-2-3-1	0.21	0.15	0.14	0.14	0.04	0.04	0.03	0.03	0.03	0.04
TE-21-10-3-3-1	0.21	0.16	0.16	0.16	0.10	0.11	0.10	0.10	0.11	0.11
TE-21-10-4-3-1	0.21	0.15	0.15	0.15	0.04	0.04	0.03	0.03	0.03	0.03
TE-21-10-5-3-1	0.23	0.15	0.14	0.15	0.03	0.04	0.03	0.04	0.03	0.02
TE-21-10-1-3-2	1.33	0.39	1.02	0.32	0.41	1.08	0.10	0.10	0.10	0.10
TE-21-10-2-3-2	1.00	0.39	0.92	0.34	0.39	0.66	0.12	0.12	0.13	0.12
TE-21-10-3-3-2	0.79	0.43	0.69	0.32	0.43	0.59	0.17	0.17	0.17	0.18
TE-21-10-4-3-2	1.31	0.46	1.13	0.33	0.45	0.79	0.09	0.10	0.11	0.11
TE-21-10-5-3-2	0.76	0.39	0.71	0.35	0.40	0.48	0.18	0.18	0.19	0.19
TE-21-10-1-3-3	1.68	0.57	1.51	0.59	0.58	1.08	0.19	0.19	0.20	0.20
TE-21-10-2-3-3	1.25	0.44	1.18	0.47	0.45	1.02	0.21	0.21	0.21	0.20
TE-21-10-3-3-3	0.94	0.39	0.93	0.41	0.42	0.72	0.21	0.22	0.21	0.21
TE-21-10-4-3-3	1.53	0.53	1.35	0.58	0.53	0.96	0.26	0.26	0.26	0.25
TE-21-10-5-3-3	0.92	0.58	0.94	0.36	0.59	0.68	0.44	0.43	0.44	0.44
TE-21-10-1-4-1	1.14	0.22	0.22	0.23	0.04	0.04	0.03	0.03	0.03	0.03
TE-21-10-2-4-1	1.13	0.22	0.22	0.22	0.03	0.03	0.04	0.04	0.03	0.03
TE-21-10-3-4-1	1.12	0.19	0.19	0.19	0.09	0.10	0.09	0.09	0.09	0.10
TE-21-10-4-4-1	1.17	0.20	0.20	0.21	0.04	0.03	0.03	0.03	0.03	0.04
TE-21-10-5-4-1	1.08	0.17	0.17	0.16	0.09	0.09	0.09	0.09	0.10	0.09
TE-21-10-1-4-2	2.21	1.53	1.85	0.43	1.51	1.55	0.15	0.14	0.14	0.14
TE-21-10-2-4-2	2.02	1.49	1.80	0.49	1.50	1.77	0.15	0.15	0.15	0.15
TE-21-10-3-4-2	1.72	1.57	1.60	0.42	1.56	1.46	0.11	0.11	0.11	0.12
TE-21-10-4-4-2	2.65	1.56	2.07	0.49	1.53	1.61	0.12	0.12	0.12	0.12
TE-21-10-5-4-2	1.62	1.50	1.48	0.44	1.47	1.34	0.32	0.32	0.32	0.32
TE-21-10-1-4-3	3.90	1.76	2.17	0.83	1.87	1.95	0.44	0.46	0.45	0.45
TE-21-10-2-4-3	2.25	1.96	2.08	0.86	1.88	2.07	0.24	0.24	0.24	0.25
TE-21-10-3-4-3	2.02	1.98	1.86	0.55	1.95	1.60	0.26	0.27	0.27	0.27
TE-21-10-4-4-3	3.22	2.11	2.30	0.82	2.07	1.97	0.21	0.21	0.22	0.21
TE-21-10-5-4-3	1.85	1.70	1.78	0.76	1.81	1.62	0.25	0.25	0.24	0.24
TE-21-10-1-5-1	16.54	0.22	0.22	0.22	0.04	0.04	0.03	0.04	0.04	0.04
TE-21-10-2-5-1	16.58	0.25	0.25	0.26	0.04	0.04	0.04	0.04	0.03	0.04
TE-21-10-3-5-1	16.36	0.25	0.25	0.24	0.14	0.15	0.14	0.14	0.14	0.14
TE-21-10-4-5-1	16.45	0.24	0.23	0.24	0.07	0.06	0.06	0.07	0.06	0.05
TE-21-10-5-5-1	16.52	0.22	0.23	0.23	0.14	0.13	0.13	0.14	0.14	0.13
TE-21-10-1-5-2	19.97	18.33	18.65	0.56	18.37	18.10	0.21	0.21	0.20	0.21
TE-21-10-2-5-2	18.29	17.86	17.89	0.62	17.85	17.87	0.23	0.22	0.22	0.21
TE-21-10-3-5-2	18.41	18.36	18.21	0.58	17.94	18.41	0.24	0.25	0.24	0.25
TE-21-10-4-5-2	22.25	17.97	19.04	0.67	18.19	18.27	0.20	0.20	0.20	0.20
TE-21-10-5-5-2	18.15	18.63	18.14	0.69	18.17	18.15	0.38	0.38	0.38	0.37
TE-21-10-1-5-3	31.24	19.58	20.38	0.96	19.31	19.49	0.31	0.30	0.30	0.30
TE-21-10-2-5-3	20.36	19.75	19.42	1.06	19.79	19.26	0.29	0.28	0.29	0.29
TE-21-10-3-5-3	19.96	19.61	20.16	0.81	19.63	19.15	0.55	0.55	0.55	0.55
TE-21-10-4-5-3	25.52	20.07	20.56	0.94	20.25	19.14	0.39	0.40	0.41	0.40
TE-21-10-5-5-3	19.47	19.20	19.16	0.82	19.08	19.27	0.80	0.79	0.80	0.80

Table A.68: Time consumation (s) for edge-disjointness on TE-21-10 instances.

	MSVND with												
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F		
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	**BOT**
TE-21-10-1-3-1	315.17	7.30	315.47	7.85	316.10	7.35	318.73	10.41	318.33	9.37	316.40	9.47	**306**
TE-21-10-2-3-1	293.90	11.50	294.00	11.22	293.87	9.30	295.77	13.60	296.00	13.67	298.13	11.46	**281**
TE-21-10-3-3-1	306.57	7.58	309.20	9.62	308.60	8.45	307.67	8.67	309.13	6.99	309.87	8.57	**296**
TE-21-10-4-3-1	288.50	9.04	287.00	7.10	288.93	9.14	283.07	11.39	287.90	10.88	286.00	8.71	**266**
TE-21-10-5-3-1	272.50	7.49	267.47	6.67	268.57	5.71	266.23	6.00	268.47	6.21	268.60	7.68	**257**
TE-21-10-1-3-2	651.00	0.00	651.00	0.00	651.00	0.00	611.07	20.04	614.40	24.92	611.67	21.00	**547**
TE-21-10-2-3-2	626.00	0.00	626.00	0.00	626.00	0.00	572.33	17.15	573.10	15.76	571.03	8.96	**520**
TE-21-10-3-3-2	842.00	0.00	842.00	0.00	842.00	0.00	590.23	18.00	589.20	17.46	591.37	17.80	**515**
TE-21-10-4-3-2	710.00	0.00	710.00	0.00	710.00	0.00	536.40	19.66	532.63	18.32	532.57	19.07	**473**
TE-21-10-5-3-2	505.00	0.00	505.00	0.00	505.00	0.00	500.47	18.74	499.27	18.73	500.47	25.66	**432**
TE-21-10-1-3-3	1035.00	0.00	1035.00	0.00	1035.00	0.00	936.27	32.02	929.43	31.55	924.77	27.84	**761**
TE-21-10-2-3-3	976.00	0.00	976.00	0.00	976.00	0.00	854.97	25.42	856.20	38.19	854.37	28.22	**721**
TE-21-10-3-3-3	1258.00	0.00	1258.00	0.00	1258.00	0.00	842.93	24.53	839.57	23.35	848.30	23.14	**743**
TE-21-10-4-3-3	918.00	0.00	918.00	0.00	918.00	0.00	788.63	28.01	791.47	19.66	786.63	29.94	**653**
TE-21-10-5-3-3	848.00	0.00	848.00	0.00	848.00	0.00	750.73	25.38	733.63	20.43	740.33	26.78	**627**
TE-21-10-1-4-1	290.97	8.02	291.07	7.52	288.30	6.57	288.23	5.81	289.17	5.05	287.90	5.68	**282**
TE-21-10-2-4-1	277.57	5.16	272.90	3.30	274.47	5.10	277.13	5.74	275.20	5.09	276.17	4.69	**271**
TE-21-10-3-4-1	280.17	7.51	279.50	6.16	278.90	4.57	279.47	8.58	283.27	9.88	277.93	6.20	**272**
TE-21-10-4-4-1	265.23	7.21	269.20	6.18	266.87	8.50	268.57	9.54	268.07	10.03	267.80	7.53	**251**
TE-21-10-5-4-1	238.70	3.42	240.07	6.35	239.73	4.22	238.87	4.54	239.93	5.49	239.57	7.56	**230**
TE-21-10-1-4-2	662.00	0.00	662.00	0.00	662.00	0.00	549.47	13.94	552.47	15.36	550.63	15.96	**458**
TE-21-10-2-4-2	574.00	0.00	574.00	0.00	574.00	0.00	541.53	14.07	540.17	13.37	540.27	12.27	**457**
TE-21-10-3-4-2	625.00	0.00	625.00	0.00	625.00	0.00	551.27	22.51	553.23	24.82	552.80	26.54	**462**
TE-21-10-4-4-2	639.00	0.00	639.00	0.00	639.00	0.00	508.53	24.06	503.00	19.38	508.00	19.35	**417**
TE-21-10-5-4-2	455.00	0.00	455.00	0.00	455.00	0.00	467.43	17.41	468.83	17.91	469.70	18.89	**371**
TE-21-10-1-4-3	874.00	0.00	874.00	0.00	874.00	0.00	849.53	38.39	843.63	37.32	848.53	24.16	**654**
TE-21-10-2-4-3	891.00	0.00	891.00	0.00	891.00	0.00	815.10	23.31	823.07	24.12	816.87	28.35	**636**
TE-21-10-3-4-3	1012.00	0.00	1012.00	0.00	1012.00	0.00	794.13	33.23	802.90	27.67	801.70	22.53	**663**
TE-21-10-4-4-3	813.00	0.00	813.00	0.00	813.00	0.00	738.10	29.57	734.73	24.80	732.60	27.25	**576**
TE-21-10-5-4-3	915.00	0.00	915.00	0.00	915.00	0.00	673.50	22.12	692.87	27.45	682.10	26.20	**549**
TE-21-10-1-5-1	278.40	6.59	277.83	6.82	278.63	7.87	277.97	5.97	277.63	7.18	277.70	8.44	**269**
TE-21-10-2-5-1	268.57	5.20	267.53	4.95	266.57	6.35	267.93	5.27	268.50	6.27	268.40	6.70	**258**
TE-21-10-3-5-1	276.33	4.56	276.80	4.78	275.83	4.21	275.37	3.69	276.70	4.07	274.57	3.45	**272**
TE-21-10-4-5-1	258.63	7.69	257.23	5.40	255.93	7.29	259.80	7.01	258.70	7.66	257.63	9.15	**238**
TE-21-10-5-5-1	225.83	7.76	223.20	4.05	224.43	5.75	224.87	6.16	226.47	6.07	224.57	4.62	**216**
TE-21-10-1-5-2	528.00	0.00	528.00	0.00	528.00	0.00	509.80	12.26	512.37	13.91	512.70	16.16	**424**
TE-21-10-2-5-2	513.00	0.00	513.00	0.00	513.00	0.00	507.40	21.50	508.83	16.18	505.70	21.31	**423**
TE-21-10-3-5-2	1016.00	0.00	1016.00	0.00	1016.00	0.00	495.27	21.66	501.27	26.19	496.30	25.61	**423**
TE-21-10-4-5-2	541.00	0.00	541.00	0.00	541.00	0.00	474.60	17.96	477.20	16.31	481.73	16.03	**377**
TE-21-10-5-5-2	557.00	0.00	557.00	0.00	557.00	0.00	408.43	18.93	414.37	18.42	408.03	17.15	**346**
TE-21-10-1-5-3	916.00	0.00	916.00	0.00	916.00	0.00	783.67	32.43	798.23	32.46	789.50	32.49	**622**
TE-21-10-2-5-3	854.00	0.00	854.00	0.00	854.00	0.00	756.83	31.75	754.83	30.01	755.67	27.17	**580**
TE-21-10-3-5-3	946.00	0.00	946.00	0.00	946.00	0.00	766.63	26.81	764.57	26.78	763.03	23.44	**625**
TE-21-10-4-5-3	737.00	0.00	737.00	0.00	737.00	0.00	696.23	33.00	692.50	30.16	698.40	24.97	**540**
TE-21-10-5-5-3	789.00	0.00	789.00	0.00	789.00	0.00	632.50	17.76	628.73	23.90	625.30	23.15	**519**

Table A.69: Results for edge-disjointness on TE-21-10 instances.

	MSVND with											
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TE-21-10-1-3-1	0.41	0.04	0.41	0.05	0.40	0.05	0.40	0.04	0.40	0.04	0.41	0.04
TE-21-10-2-3-1	0.41	0.05	0.42	0.03	0.41	0.04	0.41	0.04	0.44	0.03	0.43	0.04
TE-21-10-3-3-1	0.54	0.06	0.53	0.07	0.54	0.06	0.53	0.06	0.53	0.06	0.53	0.06
TE-21-10-4-3-1	0.40	0.04	0.38	0.04	0.40	0.04	0.38	0.04	0.40	0.04	0.37	0.04
TE-21-10-5-3-1	0.41	0.05	0.41	0.05	0.42	0.04	0.41	0.04	0.41	0.04	0.42	0.04
TE-21-10-1-3-2	3.60	0.02	3.61	0.02	3.60	0.03	1.21	0.13	1.22	0.13	1.17	0.10
TE-21-10-2-3-2	3.44	0.02	3.44	0.03	3.43	0.03	1.20	0.10	1.28	0.12	1.23	0.11
TE-21-10-3-3-2	3.92	0.02	3.93	0.03	3.92	0.03	1.44	0.15	1.47	0.14	1.44	0.14
TE-21-10-4-3-2	4.12	0.03	4.11	0.03	4.12	0.03	1.18	0.16	1.23	0.11	1.26	0.14
TE-21-10-5-3-2	3.66	0.02	3.66	0.03	3.66	0.02	1.35	0.18	1.32	0.14	1.36	0.14
TE-21-10-1-3-3	5.30	0.03	5.30	0.03	5.30	0.03	2.14	0.19	2.13	0.16	2.21	0.22
TE-21-10-2-3-3	3.96	0.03	3.96	0.03	3.96	0.03	2.33	0.18	2.31	0.26	2.33	0.15
TE-21-10-3-3-3	3.70	0.03	3.70	0.02	3.70	0.03	2.70	0.27	2.72	0.30	2.73	0.32
TE-21-10-4-3-3	4.70	0.03	4.70	0.03	4.70	0.03	2.41	0.23	2.47	0.24	2.40	0.25
TE-21-10-5-3-3	5.40	0.58	5.26	0.02	5.27	0.03	2.62	0.20	2.71	0.26	2.65	0.30
TE-21-10-1-4-1	0.49	0.04	0.49	0.05	0.49	0.06	0.48	0.05	0.49	0.05	0.49	0.06
TE-21-10-2-4-1	0.64	0.08	0.63	0.07	0.64	0.07	0.64	0.06	0.64	0.05	0.67	0.08
TE-21-10-3-4-1	0.79	0.06	0.78	0.08	0.77	0.08	0.75	0.07	0.78	0.07	0.75	0.07
TE-21-10-4-4-1	0.55	0.07	0.53	0.06	0.55	0.08	0.54	0.06	0.55	0.06	0.55	0.07
TE-21-10-5-4-1	0.63	0.06	0.65	0.07	0.62	0.06	0.62	0.08	0.61	0.08	0.63	0.08
TE-21-10-1-4-2	13.75	0.10	13.78	0.13	13.77	0.10	1.47	0.15	1.40	0.19	1.43	0.19
TE-21-10-2-4-2	13.65	0.10	13.68	0.08	13.66	0.08	1.62	0.17	1.65	0.18	1.65	0.19
TE-21-10-3-4-2	13.97	0.09	14.02	0.11	14.03	0.09	1.34	0.20	1.31	0.22	1.36	0.18
TE-21-10-4-4-2	14.20	0.09	14.19	0.10	14.20	0.09	1.41	0.21	1.36	0.19	1.36	0.19
TE-21-10-5-4-2	13.97	0.12	14.00	0.09	13.99	0.09	1.44	0.18	1.45	0.23	1.40	0.13
TE-21-10-1-4-3	16.35	0.06	16.37	0.10	16.38	0.10	2.57	0.34	2.63	0.32	2.58	0.23
TE-21-10-2-4-3	17.67	0.36	17.61	0.27	17.59	0.08	2.83	0.26	2.88	0.32	2.83	0.31
TE-21-10-3-4-3	17.41	0.10	17.43	0.14	17.43	0.09	2.92	0.38	3.09	0.40	3.04	0.49
TE-21-10-4-4-3	19.12	0.47	19.04	0.25	18.97	0.09	2.83	0.29	2.81	0.30	2.83	0.29
TE-21-10-5-4-3	15.84	0.09	15.85	0.11	15.88	0.09	2.50	0.28	2.61	0.22	2.57	0.38
TE-21-10-1-5-1	0.68	0.08	0.65	0.07	0.64	0.06	0.67	0.07	0.65	0.07	0.67	0.07
TE-21-10-2-5-1	0.83	0.09	0.83	0.08	0.86	0.10	0.86	0.10	0.84	0.07	0.85	0.06
TE-21-10-3-5-1	0.97	0.09	0.98	0.09	0.98	0.08	0.97	0.08	0.96	0.07	0.99	0.07
TE-21-10-4-5-1	0.69	0.07	0.70	0.06	0.71	0.07	0.70	0.07	0.68	0.07	0.71	0.07
TE-21-10-5-5-1	0.76	0.07	0.78	0.07	0.78	0.10	0.77	0.07	0.79	0.07	0.78	0.07
TE-21-10-1-5-2	165.42	6.14	178.69	30.54	245.26	26.45	2.33	0.32	2.19	0.27	2.19	0.24
TE-21-10-2-5-2	162.16	0.37	162.28	0.54	162.32	0.46	2.48	0.23	2.43	0.19	2.40	0.22
TE-21-10-3-5-2	162.26	0.49	162.48	0.55	162.61	0.63	2.40	0.24	2.33	0.30	2.38	0.23
TE-21-10-4-5-2	175.42	20.23	168.79	9.06	176.17	19.02	2.44	0.56	2.19	0.28	2.14	0.23
TE-21-10-5-5-2	162.70	0.46	162.89	0.52	162.96	0.56	2.60	0.29	2.71	0.34	2.72	0.27
TE-21-10-1-5-3	175.55	0.45	175.72	0.36	175.88	0.64	3.90	0.42	3.81	0.41	3.97	0.43
TE-21-10-2-5-3	176.88	0.45	177.24	0.59	177.10	0.49	4.55	0.46	4.48	0.37	4.46	0.40
TE-21-10-3-5-3	184.93	14.03	194.43	26.30	188.11	17.53	4.45	0.46	4.21	0.48	4.31	0.84
TE-21-10-4-5-3	189.12	21.05	187.21	9.49	198.09	22.85	4.62	1.12	4.04	0.51	3.96	0.37
TE-21-10-5-5-3	175.21	0.31	175.63	0.45	175.74	0.39	4.14	0.47	4.10	0.46	4.20	0.47

Table A.70: Time consumation (s) for edge-disjointness on TE-21-10 instances.

	GRASP												
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$		
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	**BOT**
TE-21-10-1-3-1	338.00	0.00	338.00	0.00	338.00	0.00	338.00	0.00	338.00	0.00	338.00	0.00	**306**
TE-21-10-2-3-1	340.00	0.00	340.00	0.00	340.00	0.00	340.00	0.00	340.00	0.00	340.00	0.00	**281**
TE-21-10-3-3-1	317.00	0.00	317.00	0.00	317.00	0.00	317.00	0.00	317.00	0.00	317.00	0.00	**296**
TE-21-10-4-3-1	308.00	0.00	308.00	0.00	308.00	0.00	308.00	0.00	308.00	0.00	308.00	0.00	**266**
TE-21-10-5-3-1	269.00	0.00	269.00	0.00	269.00	0.00	269.00	0.00	269.00	0.00	269.00	0.00	**257**
TE-21-10-1-3-2	761.67	15.13	730.13	39.71	714.43	39.74	757.67	46.35	779.13	87.25	799.77	91.43	**547**
TE-21-10-2-3-2	688.40	13.63	677.57	38.11	696.20	34.12	721.97	60.23	751.03	72.70	769.40	88.63	**520**
TE-21-10-3-3-2	615.47	37.94	635.40	35.16	683.40	36.07	725.93	57.47	785.60	99.95	811.20	100.19	**515**
TE-21-10-4-3-2	615.87	22.12	630.13	30.85	620.23	33.76	680.27	65.76	695.67	70.94	697.37	86.73	**473**
TE-21-10-5-3-2	561.27	30.84	561.90	30.01	585.97	37.68	610.47	65.61	686.17	77.91	694.83	83.95	**432**
TE-21-10-1-3-3	1074.73	49.87	1061.80	57.15	1051.40	55.83	1080.63	86.83	1119.27	91.75	1187.37	122.69	**761**
TE-21-10-2-3-3	973.23	20.67	989.67	34.00	1009.40	45.90	1005.83	75.16	1112.87	94.65	1102.87	88.29	**721**
TE-21-10-3-3-3	931.57	8.65	960.00	32.05	1000.57	42.64	1063.30	68.94	1116.97	109.70	1187.93	138.98	**743**
TE-21-10-4-3-3	894.60	28.38	897.90	41.86	906.97	57.68	956.43	80.16	1030.10	91.91	1035.27	115.28	**653**
TE-21-10-5-3-3	805.20	37.08	805.57	41.22	834.90	46.87	902.00	54.46	976.63	97.22	1021.47	129.01	**627**
TE-21-10-1-4-1	285.00	0.00	285.00	0.00	285.00	0.00	285.00	0.00	285.00	0.00	285.00	0.00	**282**
TE-21-10-2-4-1	283.00	0.00	283.00	0.00	283.00	0.00	283.00	0.00	283.00	0.00	283.00	0.00	**271**
TE-21-10-3-4-1	284.00	0.00	284.00	0.00	284.00	0.00	284.00	0.00	284.00	0.00	284.00	0.00	**272**
TE-21-10-4-4-1	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	**251**
TE-21-10-5-4-1	244.00	0.00	244.00	0.00	244.00	0.00	244.00	0.00	244.00	0.00	244.00	0.00	**230**
TE-21-10-1-4-2	599.93	18.59	621.60	35.87	621.67	43.78	746.97	74.21	773.60	82.93	812.47	113.11	**458**
TE-21-10-2-4-2	594.97	12.87	584.40	30.15	637.17	54.61	702.67	67.50	738.30	103.14	764.77	100.88	**457**
TE-21-10-3-4-2	569.83	17.77	566.67	20.87	642.30	50.82	729.30	96.84	823.80	115.14	878.50	101.18	**462**
TE-21-10-4-4-2	546.07	24.04	551.27	22.72	589.17	52.95	633.73	74.96	704.23	76.58	728.43	113.85	**417**
TE-21-10-5-4-2	444.00	7.72	475.70	38.58	531.70	47.78	590.80	69.47	700.20	124.35	714.43	125.24	**371**
TE-21-10-1-4-3	880.47	30.26	905.63	39.32	939.60	71.39	1064.40	115.58	1154.17	115.50	1184.37	135.12	**654**
TE-21-10-2-4-3	866.03	27.64	889.53	34.51	931.97	74.04	1062.77	123.05	1099.23	94.07	1125.97	81.70	**636**
TE-21-10-3-4-3	847.00	0.00	856.43	46.57	914.03	55.46	1032.87	95.55	1174.40	129.79	1233.93	173.18	**663**
TE-21-10-4-4-3	771.07	19.83	782.47	28.92	843.27	64.00	972.47	96.75	1018.30	116.21	1084.07	191.91	**576**
TE-21-10-5-4-3	670.20	9.74	699.73	37.94	748.60	70.52	886.97	96.09	986.33	148.34	1043.57	209.35	**549**
TE-21-10-1-5-1	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	**269**
TE-21-10-2-5-1	280.00	0.00	280.00	0.00	280.00	0.00	280.00	0.00	280.00	0.00	280.00	0.00	**258**
TE-21-10-3-5-1	280.00	0.00	280.00	0.00	280.00	0.00	280.00	0.00	280.00	0.00	280.00	0.00	**272**
TE-21-10-4-5-1	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	271.00	0.00	**238**
TE-21-10-5-5-1	222.00	0.00	222.00	0.00	222.00	0.00	222.00	0.00	222.00	0.00	222.00	0.00	**216**
TE-21-10-1-5-2	538.00	0.00	565.73	37.21	615.50	46.65	713.63	73.95	767.33	123.36	789.87	100.18	**424**
TE-21-10-2-5-2	543.17	12.91	556.23	21.59	624.03	61.85	719.03	74.77	754.40	85.50	754.10	109.95	**423**
TE-21-10-3-5-2	517.67	34.71	524.00	23.60	601.13	57.38	723.77	87.90	799.77	138.96	821.60	119.43	**423**
TE-21-10-4-5-2	500.07	14.22	514.23	28.87	565.90	55.17	640.93	78.76	706.63	93.87	711.77	111.82	**377**
TE-21-10-5-5-2	437.67	5.04	439.47	31.25	496.43	51.96	601.63	91.08	679.63	101.48	707.87	110.28	**346**
TE-21-10-1-5-3	873.07	6.60	839.60	33.80	904.97	65.19	1089.67	146.68	1147.73	132.85	1153.97	116.34	**622**
TE-21-10-2-5-3	779.30	4.50	821.93	23.97	898.70	64.70	1016.43	79.68	1093.03	121.36	1154.60	104.91	**580**
TE-21-10-3-5-3	754.90	25.45	799.30	41.60	892.37	68.18	1025.13	108.73	1213.10	161.57	1199.60	173.20	**625**
TE-21-10-4-5-3	705.20	23.45	724.13	41.00	820.30	73.97	943.17	101.68	986.00	100.30	1051.30	168.20	**540**
TE-21-10-5-5-3	609.13	37.24	653.33	32.53	724.33	49.92	861.87	84.45	983.00	114.37	1040.77	188.37	**519**

Table A.71: Results for edge-disjointness on TE-21-10 instances.

	GRASP											
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
TE-21-10-1-3-1	0.21	0.01	0.21	0.01	0.21	0.01	0.21	0.01	0.21	0.01	0.21	0.01
TE-21-10-2-3-1	0.21	0.01	0.20	0.01	0.21	0.01	0.21	0.01	0.20	0.01	0.21	0.01
TE-21-10-3-3-1	0.22	0.01	0.23	0.01	0.23	0.01	0.22	0.01	0.23	0.01	0.22	0.01
TE-21-10-4-3-1	0.22	0.01	0.21	0.01	0.21	0.01	0.22	0.01	0.21	0.01	0.22	0.01
TE-21-10-5-3-1	0.22	0.01	0.22	0.01	0.22	0.01	0.22	0.01	0.22	0.01	0.21	0.01
TE-21-10-1-3-2	1.27	0.02	1.23	0.11	0.97	0.20	0.71	0.17	0.63	0.10	0.65	0.17
TE-21-10-2-3-2	1.07	0.06	1.07	0.12	0.87	0.18	0.70	0.13	0.68	0.15	0.61	0.15
TE-21-10-3-3-2	0.84	0.05	0.82	0.09	0.81	0.12	0.69	0.13	0.64	0.14	0.62	0.10
TE-21-10-4-3-2	1.26	0.07	1.06	0.11	0.66	0.17	0.63	0.11	0.62	0.12	0.64	0.14
TE-21-10-5-3-2	0.72	0.03	0.72	0.11	0.70	0.12	0.76	0.20	0.63	0.13	0.63	0.12
TE-21-10-1-3-3	1.61	0.04	1.58	0.17	1.40	0.23	0.98	0.20	0.93	0.17	0.87	0.18
TE-21-10-2-3-3	1.26	0.07	1.40	0.14	1.30	0.17	1.02	0.18	0.90	0.18	0.91	0.17
TE-21-10-3-3-3	1.10	0.06	1.05	0.11	1.15	0.17	1.00	0.23	0.88	0.17	0.85	0.18
TE-21-10-4-3-3	1.41	0.09	1.35	0.14	1.00	0.20	0.92	0.21	0.87	0.12	0.91	0.13
TE-21-10-5-3-3	0.91	0.06	0.95	0.09	0.91	0.18	0.93	0.21	0.93	0.17	0.99	0.18
TE-21-10-1-4-1	1.18	0.04	1.18	0.03	1.18	0.03	1.18	0.03	1.17	0.03	1.18	0.03
TE-21-10-2-4-1	1.17	0.03	1.18	0.04	1.18	0.03	1.17	0.04	1.17	0.04	1.17	0.02
TE-21-10-3-4-1	1.14	0.03	1.14	0.03	1.14	0.03	1.14	0.03	1.14	0.03	1.15	0.03
TE-21-10-4-4-1	1.17	0.03	1.16	0.03	1.15	0.03	1.16	0.04	1.17	0.04	1.16	0.04
TE-21-10-5-4-1	1.14	0.02	1.14	0.04	1.12	0.03	1.13	0.03	1.13	0.03	1.13	0.03
TE-21-10-1-4-2	2.21	0.09	2.34	0.27	1.97	0.29	1.66	0.17	1.64	0.20	1.70	0.22
TE-21-10-2-4-2	1.96	0.06	1.96	0.18	1.78	0.22	1.70	0.38	1.72	0.25	1.63	0.15
TE-21-10-3-4-2	1.68	0.08	1.81	0.17	1.58	0.12	1.83	0.41	1.68	0.21	1.69	0.24
TE-21-10-4-4-2	2.78	0.09	2.29	0.26	1.87	0.31	1.72	0.19	1.68	0.14	1.68	0.17
TE-21-10-5-4-2	1.55	0.04	1.62	0.12	1.58	0.11	1.69	0.20	1.64	0.18	1.67	0.16
TE-21-10-1-4-3	3.71	0.15	3.06	0.46	3.00	0.56	2.16	0.26	2.16	0.24	2.08	0.28
TE-21-10-2-4-3	2.34	0.13	2.54	0.44	2.58	0.49	2.19	0.37	2.17	0.35	2.16	0.39
TE-21-10-3-4-3	2.04	0.05	2.18	0.18	2.11	0.22	2.44	0.77	2.20	0.31	2.13	0.30
TE-21-10-4-4-3	3.25	0.13	2.90	0.46	2.33	0.41	2.18	0.37	2.15	0.25	2.14	0.33
TE-21-10-5-4-3	1.85	0.05	1.86	0.13	1.98	0.20	2.27	0.43	2.15	0.29	2.14	0.30
TE-21-10-1-5-1	16.54	0.16	16.57	0.25	16.56	0.14	16.53	0.13	16.45	0.14	18.51	2.04
TE-21-10-2-5-1	16.48	0.23	16.79	0.66	16.49	0.12	16.48	0.18	16.53	0.31	16.55	0.26
TE-21-10-3-5-1	16.53	0.13	16.58	0.12	16.59	0.16	16.55	0.14	17.16	1.52	16.57	0.14
TE-21-10-4-5-1	16.37	0.13	16.45	0.12	16.42	0.13	16.41	0.13	17.68	1.48	16.45	0.54
TE-21-10-5-5-1	16.54	0.16	16.51	0.17	16.55	0.12	16.55	0.15	16.53	0.15	16.52	0.16
TE-21-10-1-5-2	21.21	3.61	20.02	1.05	28.10	4.05	22.30	4.91	18.29	0.31	18.41	0.58
TE-21-10-2-5-2	18.21	0.17	18.67	0.76	18.38	0.53	18.27	0.43	18.17	0.55	18.32	0.51
TE-21-10-3-5-2	18.53	0.27	18.41	0.25	18.38	0.36	18.54	0.43	18.46	0.75	18.50	1.00
TE-21-10-4-5-2	26.24	5.35	21.36	3.18	20.73	3.93	18.47	1.06	21.78	2.95	21.46	1.93
TE-21-10-5-5-2	18.32	0.14	18.31	0.22	18.39	0.24	18.40	0.33	18.47	0.34	18.46	0.38
TE-21-10-1-5-3	29.64	1.05	24.91	3.87	24.21	3.50	20.15	1.14	20.28	1.19	20.05	0.75
TE-21-10-2-5-3	20.16	0.22	21.16	1.76	22.21	2.51	20.59	1.45	20.38	1.64	19.98	0.63
TE-21-10-3-5-3	20.03	0.38	20.49	0.96	20.13	0.85	20.16	0.64	20.57	2.11	20.24	1.21
TE-21-10-4-5-3	27.65	3.35	24.42	2.28	21.06	1.65	20.86	1.85	20.29	0.70	21.60	1.74
TE-21-10-5-5-3	19.46	0.14	19.49	0.25	19.88	0.47	20.53	0.88	20.02	0.45	20.31	0.69

Table A.72: Time consumation (s) for edge-disjointness on TE-21-10 instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
dfn-gwin-3-1	59216	59216	59216	59216	15684	15684	15684	15684	15684	15684
dfn-gwin-3-2	19388	74936	25732	74936	74936	22872	28616	28616	28616	28616
dfn-gwin-4-1	47360	47360	47360	47360	13964	13964	13964	13964	13964	13964
dfn-gwin-4-2	18136	74936	18136	74936	74936	18136	19212	19212	19212	19212
dfn-gwin-5-1	47360	47360	47360	47360	10552	10552	10552	10552	10552	10552
dfn-gwin-5-2	14364	74936	16692	74936	74936	15440	18108	18108	18108	18108
di-yuan-3-1	803900	803900	803900	803900	575200	575200	575200	575200	575200	575200
di-yuan-3-2	723700	2373200	975200	1381400	2373200	820100	861200	861200	861200	861200
di-yuan-3-3	980800	2549200	1166600	2356400	2549200	1111300	1248300	1248300	1248300	1248300
di-yuan-4-1	695900	695900	695900	695900	397400	397400	397400	397400	397400	397400
di-yuan-4-2	532100	2142600	737200	1531400	2142600	585800	680000	680000	680000	680000
di-yuan-4-3	756200	2489200	865200	2356400	2489200	865200	1136300	1136300	1136300	1136300
di-yuan-5-1	695900	695900	695900	695900	313400	313400	313400	313400	313400	313400
di-yuan-5-2	470200	2361400	644300	1531400	2361400	573900	623800	623800	623800	623800
di-yuan-5-3	726600	2594200	819900	2356400	2594200	762300	983400	983400	983400	983400
nobel-us-3-1	189130	189130	189130	189130	189130	189130	189130	189130	189130	189130
nobel-us-4-1	189130	189130	189130	189130	163770	163770	163770	163770	163770	163770
nobel-us-5-1	189130	189130	189130	189130	127800	127800	127800	127800	127800	127800
nobel-us-5-2	169070	189130	189130	189130	189130	182110	189130	189130	189130	189130
pdh-3-1	2712178	2712178	2712178	2712178	1161941	1161941	1161941	1161941	1161941	1161941
pdh-3-2	1750937	3894782	1981928	3034152	3894782	1981928	2259639	2259639	2259639	2259639
pdh-3-3	2395857	4210043	2736116	3331128	4210043	2628968	2955376	2955376	2955376	2955376
pdh-4-1	2712178	2712178	2712178	2712178	1092414	1092414	1092414	1092414	1092414	1092414
pdh-4-2	1499276	3834362	1719402	3034152	3834362	1719402	1864975	1864975	1864975	1864975
pdh-4-3	2169260	4210043	2595578	3331128	4210043	2595578	2497970	2497970	2497970	2497970
pdh-5-1	2712178	2712178	2712178	2712178	1008398	1008398	1008398	1008398	1008398	1008398
pdh-5-2	1487616	3834362	1594764	3034152	3834362	1594764	1876105	1876105	1876105	1876105
pdh-5-3	2061394	4024455	2329342	3331128	4024455	2215569	2611743	2611743	2611743	2611743
polska-4-1	4125	4125	4125	4125	3820	3820	3820	3820	3820	3820
polska-5-1	4125	4125	4125	4125	2930	2930	2930	2930	2930	2930
polska-5-2	3761	4125	4125	4125	4125	4125	4125	4125	4125	4125

Table A.73: Results for edge-disjointness on SNDlib instances.

	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C3-S1	C3-S2	C3-S3F
dfn-gwin-3-1	0.06	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02
dfn-gwin-3-2	0.29	0.05	0.31	0.02	0.05	0.29	0.02	0.03	0.02	0.02
dfn-gwin-4-1	0.16	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02
dfn-gwin-4-2	0.34	0.18	0.46	0.03	0.17	0.42	0.02	0.02	0.03	0.02
dfn-gwin-5-1	0.82	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.03	0.02
dfn-gwin-5-2	1.21	0.92	1.21	0.02	0.89	1.27	0.03	0.03	0.04	0.03
di-yuan-3-1	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01
di-yuan-3-2	0.20	0.01	0.15	0.01	0.02	0.14	0.00	0.00	0.00	0.00
di-yuan-3-3	0.21	0.01	0.19	0.01	0.01	0.16	0.02	0.00	0.01	0.00
di-yuan-4-1	0.04	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00
di-yuan-4-2	0.28	0.03	0.17	0.02	0.04	0.13	0.01	0.01	0.00	0.01
di-yuan-4-3	0.29	0.03	0.21	0.01	0.04	0.18	0.01	0.02	0.02	0.01
di-yuan-5-1	0.16	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
di-yuan-5-2	0.48	0.16	0.32	0.02	0.16	0.23	0.01	0.01	0.00	0.01
di-yuan-5-3	0.53	0.15	0.39	0.01	0.15	0.32	0.02	0.00	0.01	0.01
nobel-us-3-1	0.06	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02
nobel-us-4-1	0.08	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03
nobel-us-5-1	0.11	0.04	0.04	0.03	0.03	0.04	0.04	0.04	0.04	0.04
nobel-us-5-2	0.59	0.07	0.73	0.05	0.08	0.64	0.05	0.05	0.05	0.05
pdh-3-1	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00
pdh-3-2	0.15	0.00	0.06	0.00	0.01	0.07	0.00	0.00	0.00	0.01
pdh-3-3	0.18	0.00	0.11	0.00	0.01	0.11	0.01	0.01	0.01	0.00
pdh-4-1	0.03	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01
pdh-4-2	0.10	0.02	0.11	0.01	0.02	0.09	0.01	0.01	0.00	0.01
pdh-4-3	0.22	0.03	0.17	0.01	0.03	0.16	0.01	0.01	0.01	0.01
pdh-5-1	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
pdh-5-2	0.19	0.06	0.18	0.00	0.06	0.15	0.01	0.01	0.01	0.02
pdh-5-3	0.31	0.08	0.23	0.01	0.07	0.27	0.01	0.02	0.01	0.01
polska-4-1	0.03	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.01
polska-5-1	0.06	0.02	0.03	0.02	0.02	0.01	0.02	0.02	0.03	0.02
polska-5-2	0.40	0.04	0.34	0.03	0.03	0.32	0.03	0.04	0.02	0.04

Table A.74: Time consumation (s) for edge-disjointness on SNDlib instances.

	VND with									
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C4-S1	C4-S2	C4-S3F
dfn-gwin-3-1	19052	19052	19052	19052	15684	15684	15684	15684	15684	15684
dfn-gwin-3-2	19388	49904	24168	34376	49904	22872	28616	28616	28616	28616
dfn-gwin-4-1	14044	14044	14044	14044	13964	13964	13964	13964	13964	13964
dfn-gwin-4-2	18136	51492	18136	29212	51492	18136	19212	19212	19212	19212
dfn-gwin-5-1	10864	10864	10864	10864	10552	10552	10552	10552	10552	10552
dfn-gwin-5-2	14364	52556	16692	27352	52556	15440	18108	18108	18108	18108
di-yuan-3-1	384400	384400	384400	384400	545200	545200	545200	545200	545200	545200
di-yuan-3-2	723700	1586900	879900	1014000	1586900	820100	798600	798600	798600	798600
di-yuan-3-3	980800	1855400	1116600	1566800	1855400	1111300	1248300	1248300	1248300	1248300
di-yuan-4-1	329500	329500	329500	329500	387400	387400	387400	387400	387400	387400
di-yuan-4-2	532100	1739300	656200	816300	1739300	585800	680000	680000	680000	680000
di-yuan-4-3	756200	1975700	865200	1254800	1975700	865200	1136300	1136300	1136300	1136300
di-yuan-5-1	304100	304100	304100	304100	313400	313400	313400	313400	313400	313400
di-yuan-5-2	470200	1412800	604300	816300	1412800	573900	623800	623800	623800	623800
di-yuan-5-3	726600	1931800	784200	1249500	1931800	762300	983400	983400	983400	983400
nobel-us-3-1	189130	189130	189130	189130	189130	189130	189130	189130	189130	189130
nobel-us-4-1	176090	176090	176090	176090	163770	163770	163770	163770	163770	163770
nobel-us-5-1	176090	176090	176090	176090	127800	127800	127800	127800	127800	127800
nobel-us-5-2	169070	189130	189130	189130	189130	182110	189130	189130	189130	189130
pdh-3-1	1229322	1229322	1229322	1229322	1032533	1032533	1032533	1032533	1032533	1032533
pdh-3-2	1750937	3069705	1981928	2265124	3069705	1981928	2129436	2129436	2129436	2129436
pdh-3-3	2395857	3541820	2736116	3026997	3541820	2628968	2852733	2852733	2852733	2852733
pdh-4-1	1022676	1022676	1022676	1022676	1092414	1092414	1092414	1092414	1092414	1092414
pdh-4-2	1499276	2950483	1719402	1982193	2950483	1719402	1864975	1864975	1864975	1864975
pdh-4-3	2169260	3608671	2466170	2740886	3608671	2595578	2497970	2497970	2497970	2497970
pdh-5-1	1022676	1022676	1022676	1022676	1008398	1008398	1008398	1008398	1008398	1008398
pdh-5-2	1487616	2931386	1594764	1982193	2931386	1594764	1871600	1871600	1871600	1871600
pdh-5-3	2061394	3839326	2329342	2483395	3839326	2215569	2611743	2611743	2611743	2611743
polska-4-1	3820	3820	3820	3820	3820	3820	3820	3820	3820	3820
polska-5-1	3202	3202	3202	3202	2930	2930	2930	2930	2930	2930
polska-5-2	3761	4125	4125	4125	4125	4125	4125	4125	4125	4125

Table A.75: Results for edge-disjointness on SNDlib instances.

	VND with									
	C1	C2-S1	C2-S2	C2-S3F	C3-S1	C3-S2	C3-S3F	C3-S1	C3-S2	C3-S3F
dfn-gwin-3-1	1.39	1.36	1.34	1.37	0.07	0.07	0.06	0.07	0.07	0.07
dfn-gwin-3-2	0.38	1.75	0.47	2.23	1.76	0.39	0.11	0.11	0.11	0.10
dfn-gwin-4-1	1.49	1.34	1.33	1.35	0.07	0.07	0.08	0.07	0.08	0.08
dfn-gwin-4-2	0.47	2.76	0.57	3.59	2.71	0.52	0.12	0.12	0.12	0.12
dfn-gwin-5-1	2.83	2.10	2.09	2.07	0.08	0.09	0.08	0.09	0.08	0.08
dfn-gwin-5-2	1.27	8.31	1.34	9.33	8.66	1.41	0.14	0.13	0.14	0.14
di-yuan-3-1	0.17	0.16	0.15	0.14	0.05	0.05	0.05	0.05	0.05	0.05
di-yuan-3-2	0.22	0.36	0.23	0.19	0.36	0.18	0.09	0.10	0.09	0.09
di-yuan-3-3	0.26	0.50	0.28	0.49	0.52	0.22	0.05	0.05	0.05	0.06
di-yuan-4-1	0.16	0.13	0.13	0.13	0.03	0.03	0.03	0.04	0.04	0.04
di-yuan-4-2	0.30	0.28	0.28	0.35	0.29	0.17	0.05	0.04	0.04	0.04
di-yuan-4-3	0.35	0.66	0.29	0.79	0.65	0.22	0.07	0.07	0.07	0.07
di-yuan-5-1	0.30	0.17	0.17	0.18	0.03	0.02	0.03	0.03	0.03	0.03
di-yuan-5-2	0.53	1.17	0.41	0.42	1.20	0.32	0.05	0.05	0.05	0.05
di-yuan-5-3	0.61	1.59	0.59	1.14	1.52	0.41	0.08	0.08	0.07	0.08
nobel-us-3-1	0.15	0.11	0.11	0.11	0.11	0.12	0.11	0.12	0.11	0.11
nobel-us-4-1	0.31	0.26	0.27	0.26	0.13	0.14	0.13	0.14	0.14	0.14
nobel-us-5-1	0.37	0.30	0.29	0.31	0.17	0.17	0.16	0.17	0.16	0.17
nobel-us-5-2	0.84	0.34	0.98	0.28	0.34	0.90	0.28	0.27	0.27	0.28
pdh-3-1	0.29	0.28	0.28	0.28	0.03	0.04	0.04	0.03	0.04	0.03
pdh-3-2	0.18	0.22	0.12	0.26	0.22	0.11	0.07	0.08	0.08	0.06
pdh-3-3	0.22	0.18	0.16	0.14	0.18	0.16	0.11	0.10	0.10	0.10
pdh-4-1	0.35	0.33	0.32	0.33	0.02	0.02	0.02	0.02	0.03	0.02
pdh-4-2	0.16	0.27	0.15	0.33	0.27	0.13	0.04	0.04	0.04	0.04
pdh-4-3	0.28	0.31	0.26	0.29	0.32	0.20	0.06	0.06	0.06	0.06
pdh-5-1	0.41	0.34	0.35	0.36	0.03	0.03	0.02	0.02	0.02	0.03
pdh-5-2	0.21	0.50	0.20	0.39	0.50	0.20	0.10	0.10	0.09	0.09
pdh-5-3	0.37	0.32	0.30	0.41	0.30	0.33	0.06	0.07	0.07	0.08
polska-4-1	0.19	0.15	0.16	0.16	0.07	0.08	0.08	0.09	0.08	0.08
polska-5-1	0.40	0.34	0.35	0.36	0.09	0.10	0.09	0.09	0.09	0.09
polska-5-2	0.53	0.21	0.51	0.16	0.21	0.48	0.17	0.18	0.17	0.16

Table A.76: Time consumation (s) for edge-disjointness on SNDlib instances.

	MSVND with											
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
dfn-gwin-3-1	13771.47	1146.58	14023.60	1119.87	13442.67	1105.50	13458.80	1293.80	13968.13	1172.69	14099.20	1242.47
dfn-gwin-3-2	49904.00	0.00	49904.00	0.00	49904.00	0.00	22966.00	1052.08	23047.33	1046.09	23312.00	884.70
dfn-gwin-4-1	10436.27	524.81	10610.93	479.12	10707.60	657.17	10460.67	505.64	10658.53	593.96	10472.13	668.68
dfn-gwin-4-2	51492.00	0.00	51492.00	0.00	51492.00	0.00	18300.93	637.63	18292.40	488.00	18282.27	605.08
dfn-gwin-5-1	9467.87	546.00	9417.73	590.16	9419.33	432.61	9315.20	700.63	9296.00	494.44	9254.40	547.59
dfn-gwin-5-2	52556.00	0.00	52556.00	0.00	52556.00	0.00	17158.00	545.94	16720.27	582.43	16935.47	736.43
di-yuan-3-1	376723.33	13656.87	379356.67	16347.26	377000.00	13672.95	382953.33	15004.89	377763.33	14592.38	378040.00	16289.00
di-yuan-3-2	1586900.00	0.00	1586900.00	0.00	1586900.00	0.00	750033.33	22341.06	746586.67	18302.92	731590.00	26392.06
di-yuan-3-3	1855400.00	0.00	1855400.00	0.00	1855400.00	0.00	1076276.67	30685.12	1069903.33	31589.53	1062070.00	32426.15
di-yuan-4-1	310576.67	14505.19	305943.33	12809.31	308426.67	15266.50	311130.00	15886.02	309100.00	13426.68	307140.00	14395.99
di-yuan-4-2	1739300.00	0.00	1739300.00	0.00	1739300.00	0.00	603436.67	20605.25	602146.67	27486.55	599266.67	26719.91
di-yuan-4-3	1975700.00	0.00	1975700.00	0.00	1975700.00	0.00	856726.67	30666.95	859223.33	30413.40	867610.00	30571.64
di-yuan-5-1	275683.33	6203.73	275126.67	3783.17	276040.00	4819.97	275333.33	3319.78	275006.67	3660.97	275263.33	4811.95
di-yuan-5-2	1412800.00	0.00	1412800.00	0.00	1412800.00	0.00	547176.67	14472.23	545006.67	12468.72	547783.33	12842.55
di-yuan-5-3	1931800.00	0.00	1931800.00	0.00	1931800.00	0.00	791663.33	31983.64	808553.33	27903.49	811686.67	24649.58
nobel-us-3-1	189130.00	0.00	189130.00	0.00	189130.00	0.00	189130.00	0.00	189130.00	0.00	189130.00	0.00
nobel-us-4-1	159623.67	3942.18	160478.67	4145.40	159838.67	4165.83	158764.33	3646.68	159542.67	4001.23	159432.67	4227.00
nobel-us-5-1	118715.33	2956.71	119179.33	4315.55	118557.67	3203.13	117960.67	3319.23	119030.33	3921.15	118509.67	2613.09
nobel-us-5-2	189130.00	0.00	189130.00	0.00	189130.00	0.00	173525.00	1193.38	173219.67	1444.10	172952.00	1241.60
pdh-3-1	1105819.43	35147.04	1102550.43	27964.85	1087342.47	43253.79	1091776.30	31372.87	1106659.10	39084.53	1106365.67	34181.17
pdh-3-2	3069705.00	0.00	3069705.00	0.00	3069705.00	0.00	1988023.20	68907.58	1987892.97	51779.36	1998506.67	56204.96
pdh-3-3	3541820.00	0.00	3541820.00	0.00	3541820.00	0.00	2786122.47	75301.94	2782456.07	64680.66	2776048.47	68042.40
pdh-4-1	1029195.27	45578.42	1038535.27	42381.62	1033711.10	42302.82	1033769.60	37649.20	1030263.53	44829.30	1030495.80	41366.10
pdh-4-2	2950483.00	0.00	2950483.00	0.00	2950483.00	0.00	1802967.37	66546.18	1813916.63	59735.39	1799307.77	44477.85
pdh-4-3	3608671.00	0.00	3608671.00	0.00	3608671.00	0.00	2451126.70	58920.22	2451965.73	53633.21	2462018.13	64348.16
pdh-5-1	983986.97	39861.56	994080.93	43647.59	984783.83	38907.50	975111.23	38990.40	980872.03	37999.83	1008751.90	40935.66
pdh-5-2	2931386.00	0.00	2931386.00	0.00	2931386.00	0.00	1729082.27	58970.17	1724793.63	50170.15	1723222.37	60372.07
pdh-5-3	3839326.00	0.00	3839326.00	0.00	3839326.00	0.00	2335576.53	81294.43	2328000.37	78172.37	2351526.60	65345.86
polska-4-1	3091.03	153.26	3078.50	148.83	3096.30	159.42	3104.73	159.58	3130.70	157.09	3130.20	188.63
polska-5-1	2365.73	106.31	2412.23	146.02	2373.13	119.31	2373.33	107.45	2414.47	119.13	2366.80	123.27
polska-5-2	4125.00	0.00	4125.00	0.00	4125.00	0.00	3893.77	93.18	3900.83	105.86	3915.60	92.73

Table A.77: Results for edge-disjointness on SNDlib instances.

	MSVND with											
	RC3-S1		RC3-S2		RC3-S3F		RC4-S1		RC4-S2		RC4-S3F	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
dfn-gwin-3-1	0.70	0.06	0.68	0.05	0.70	0.05	0.72	0.07	0.71	0.06	0.70	0.07
dfn-gwin-3-2	15.87	0.05	15.87	0.06	15.87	0.05	1.04	0.05	1.04	0.06	1.03	0.05
dfn-gwin-4-1	0.71	0.05	0.70	0.05	0.70	0.05	0.70	0.05	0.71	0.06	0.70	0.05
dfn-gwin-4-2	24.72	0.12	24.71	0.12	24.73	0.13	1.16	0.07	1.13	0.02	1.15	0.05
dfn-gwin-5-1	0.76	0.04	0.76	0.04	0.77	0.05	0.75	0.04	0.76	0.04	0.76	0.03
dfn-gwin-5-2	76.35	0.26	76.39	0.25	76.50	0.29	1.29	0.04	1.29	0.03	1.30	0.04
di-yuan-3-1	0.31	0.04	0.32	0.05	0.32	0.04	0.33	0.04	0.33	0.04	0.32	0.05
di-yuan-3-2	3.26	0.01	3.25	0.02	3.26	0.02	0.46	0.05	0.47	0.06	0.46	0.07
di-yuan-3-3	4.65	0.02	4.65	0.02	4.65	0.02	0.60	0.05	0.59	0.06	0.58	0.04
di-yuan-4-1	0.28	0.03	0.28	0.03	0.28	0.02	0.29	0.03	0.28	0.03	0.28	0.04
di-yuan-4-2	2.61	0.03	2.60	0.03	2.60	0.03	0.51	0.08	0.50	0.06	0.50	0.06
di-yuan-4-3	5.87	0.04	5.86	0.04	5.88	0.04	0.69	0.05	0.69	0.05	0.68	0.04
di-yuan-5-1	0.28	0.02	0.27	0.02	0.27	0.02	0.27	0.02	0.28	0.02	0.28	0.02
di-yuan-5-2	10.72	0.08	10.70	0.08	10.70	0.08	0.60	0.08	0.56	0.06	0.61	0.08
di-yuan-5-3	13.98	0.11	13.98	0.09	13.98	0.10	0.86	0.11	0.85	0.09	0.84	0.09
nobel-us-3-1	1.06	0.01	1.06	0.01	1.06	0.00	1.06	0.01	1.06	0.01	1.06	0.01
nobel-us-4-1	1.32	0.07	1.30	0.05	1.35	0.09	1.33	0.07	1.34	0.08	1.33	0.09
nobel-us-5-1	1.55	0.09	1.55	0.08	1.53	0.07	1.53	0.09	1.55	0.07	1.56	0.09
nobel-us-5-2	3.10	0.01	3.10	0.01	3.10	0.01	2.58	0.02	2.58	0.02	2.58	0.02
pdh-3-1	0.29	0.04	0.28	0.03	0.30	0.03	0.30	0.05	0.30	0.03	0.30	0.03
pdh-3-2	2.00	0.01	2.01	0.01	2.01	0.01	0.53	0.09	0.52	0.08	0.49	0.09
pdh-3-3	1.59	0.01	1.60	0.01	1.68	0.19	0.60	0.08	0.57	0.06	0.59	0.10
pdh-4-1	0.27	0.03	0.27	0.03	0.27	0.03	0.28	0.04	0.28	0.02	0.28	0.03
pdh-4-2	2.54	0.02	2.55	0.02	2.55	0.02	0.48	0.07	0.48	0.08	0.48	0.07
pdh-4-3	2.86	0.02	2.86	0.02	2.86	0.02	0.68	0.09	0.68	0.08	0.70	0.10
pdh-5-1	0.27	0.02	0.28	0.03	0.29	0.03	0.28	0.03	0.28	0.02	0.29	0.03
pdh-5-2	4.40	0.05	4.40	0.06	4.43	0.05	0.62	0.11	0.63	0.10	0.60	0.10
pdh-5-3	2.75	0.04	2.74	0.04	2.74	0.03	0.94	0.13	0.96	0.19	0.96	0.14
polska-4-1	0.82	0.07	0.81	0.06	0.82	0.06	0.82	0.06	0.83	0.06	0.82	0.06
polska-5-1	0.88	0.03	0.89	0.04	0.87	0.02	0.88	0.03	0.88	0.03	0.89	0.03
polska-5-2	1.95	0.01	1.95	0.01	1.95	0.01	1.63	0.12	1.64	0.11	1.64	0.11

Table A.78: Time consumation (s) for edge-disjointness on SNDlib instances.

	GRASP											
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
dfn-gwin-3-1	19052.00	0.00	19052.00	0.00	19052.00	0.00	19052.00	0.00	19052.00	0.00	19052.00	0.00
dfn-gwin-3-2	19388.00	0.00	19766.93	683.26	20763.07	1474.41	22146.40	1686.93	25720.93	1742.13	27663.60	2282.90
dfn-gwin-4-1	14044.00	0.00	14044.00	0.00	14044.00	0.00	14044.00	0.00	14044.00	0.00	14044.00	0.00
dfn-gwin-4-2	18136.00	0.00	17258.13	634.37	17654.00	771.34	18684.00	1368.65	21799.07	1614.63	23542.53	1835.60
dfn-gwin-5-1	10864.00	0.00	10864.00	0.00	10864.00	0.00	10864.00	0.00	10864.00	0.00	10864.00	0.00
dfn-gwin-5-2	14364.00	0.00	14458.00	563.49	15847.47	717.66	16472.27	1080.23	19535.33	1638.47	21041.60	2248.38
di-yuan-3-1	384400.00	0.00	384400.00	0.00	384400.00	0.00	384400.00	0.00	384400.00	0.00	384400.00	0.00
di-yuan-3-2	736176.67	17752.53	742040.00	31614.82	805020.00	41127.67	936666.67	70683.77	1034623.33	89421.04	1093446.67	116984.70
di-yuan-3-3	980800.00	0.00	1012690.00	23963.41	1037186.67	31946.29	1168096.67	64129.72	1291320.00	80607.98	1414563.33	106425.41
di-yuan-4-1	329500.00	0.00	329500.00	0.00	329500.00	0.00	329500.00	0.00	329500.00	0.00	329500.00	0.00
di-yuan-4-2	532100.00	0.00	564863.33	23799.41	640296.67	38558.05	798633.33	79265.67	887956.67	96044.73	945473.33	86636.17
di-yuan-4-3	747920.00	6876.17	783886.67	33824.24	853843.33	36706.94	972450.00	79565.56	1069296.67	76975.30	1164773.33	115881.93
di-yuan-5-1	304100.00	0.00	304100.00	0.00	304100.00	0.00	304100.00	0.00	304100.00	0.00	304100.00	0.00
di-yuan-5-2	470200.00	0.00	507270.00	26138.82	597133.33	44106.96	727700.00	68551.04	811690.00	104071.43	852866.67	110895.68
di-yuan-5-3	710600.00	23014.24	715883.33	25616.25	804723.33	48983.25	929493.33	79679.39	1015413.33	70498.65	1128973.33	139609.30
nobel-us-3-1	189130.00	0.00	189130.00	0.00	189130.00	0.00	189130.00	0.00	189130.00	0.00	189130.00	0.00
nobel-us-4-1	176090.00	0.00	176090.00	0.00	176090.00	0.00	176090.00	0.00	176090.00	0.00	176090.00	0.00
nobel-us-5-1	176090.00	0.00	176090.00	0.00	176090.00	0.00	176090.00	0.00	176090.00	0.00	176090.00	0.00
nobel-us-5-2	169070.00	0.00	169385.33	421.51	170087.67	1208.25	169786.67	1153.44	173112.00	3320.41	173843.00	3045.48
pdh-3-1	1229322.00	0.00	1229322.00	0.00	1229322.00	0.00	1229322.00	0.00	1229322.00	0.00	1229322.00	0.00
pdh-3-2	1750937.00	0.00	1795890.53	56614.19	1827725.67	62846.43	1939788.47	92081.82	2019564.93	88410.66	2161651.60	126725.64
pdh-3-3	2395857.00	0.00	2417551.60	44130.95	2428369.97	78533.16	2497772.53	78047.78	2520125.00	84408.43	2718308.73	119131.04
pdh-4-1	1022676.00	0.00	1022676.00	0.00	1022676.00	0.00	1022676.00	0.00	1022676.00	0.00	1022676.00	0.00
pdh-4-2	1499276.00	0.00	1534906.67	65981.64	1625172.40	77540.46	1737057.80	74275.61	1782342.47	75948.50	1875164.53	85953.63
pdh-4-3	2169260.00	0.00	2208140.17	38180.91	2225099.57	93245.38	2212566.47	91244.27	2216470.33	74426.86	2295588.20	113673.81
pdh-5-1	1022676.00	0.00	1022676.00	0.00	1022676.00	0.00	1022676.00	0.00	1022676.00	0.00	1022676.00	0.00
pdh-5-2	1487616.00	0.00	1517094.20	108545.55	1557103.87	76511.21	1584778.83	84730.12	1662312.57	62569.76	1732142.13	78747.57
pdh-5-3	2061394.00	0.00	2061740.00	42607.97	2070128.67	52336.84	2096016.30	56103.34	2083688.77	115789.77	2175092.30	91939.04
polska-4-1	3820.00	0.00	3820.00	0.00	3820.00	0.00	3820.00	0.00	3820.00	0.00	3820.00	0.00
polska-5-1	3202.00	0.00	3202.00	0.00	3202.00	0.00	3202.00	0.00	3202.00	0.00	3202.00	0.00
polska-5-2	3761.00	0.00	3770.90	13.23	3776.30	13.61	3776.30	13.61	3770.90	13.23	3774.50	13.73

Table A.79: Results for edge-disjointness on SNDlib instances.

	GRASP											
	$\alpha = 0.0$		$\alpha = 0.2$		$\alpha = 0.4$		$\alpha = 0.6$		$\alpha = 0.8$		$\alpha = 1.0$	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
dfn-gwin-3-1	1.40	0.01	1.40	0.01	1.41	0.01	1.41	0.01	1.40	0.01	1.40	0.01
dfn-gwin-3-2	0.38	0.01	0.40	0.04	0.41	0.06	0.42	0.05	0.63	0.18	0.77	0.30
dfn-gwin-4-1	1.49	0.02	1.49	0.02	1.49	0.02	1.49	0.02	1.49	0.02	1.50	0.02
dfn-gwin-4-2	0.47	0.01	0.51	0.05	0.53	0.08	0.58	0.08	0.87	0.32	1.06	0.62
dfn-gwin-5-1	2.88	0.04	2.90	0.04	2.91	0.04	2.90	0.03	2.88	0.04	2.91	0.04
dfn-gwin-5-2	1.31	0.03	1.31	0.08	1.31	0.10	1.38	0.11	2.41	1.03	3.05	1.73
di-yuan-3-1	0.16	0.01	0.16	0.00	0.16	0.01	0.16	0.01	0.16	0.01	0.16	0.01
di-yuan-3-2	0.22	0.01	0.23	0.03	0.22	0.02	0.17	0.03	0.17	0.04	0.16	0.04
di-yuan-3-3	0.25	0.01	0.29	0.02	0.29	0.04	0.25	0.04	0.24	0.04	0.22	0.03
di-yuan-4-1	0.16	0.01	0.16	0.01	0.16	0.01	0.16	0.01	0.16	0.01	0.16	0.01
di-yuan-4-2	0.31	0.01	0.29	0.03	0.27	0.05	0.22	0.06	0.22	0.06	0.21	0.04
di-yuan-4-3	0.35	0.02	0.38	0.04	0.37	0.05	0.32	0.05	0.35	0.07	0.31	0.05
di-yuan-5-1	0.32	0.01	0.31	0.01	0.31	0.01	0.32	0.01	0.31	0.02	0.32	0.01
di-yuan-5-2	0.51	0.02	0.53	0.10	0.48	0.10	0.40	0.08	0.39	0.07	0.37	0.07
di-yuan-5-3	0.57	0.02	0.67	0.10	0.65	0.14	0.59	0.17	0.59	0.13	0.52	0.09
nobel-us-3-1	0.15	0.01	0.15	0.01	0.15	0.00	0.15	0.01	0.15	0.00	0.15	0.01
nobel-us-4-1	0.32	0.00	0.32	0.00	0.32	0.01	0.32	0.00	0.32	0.01	0.32	0.00
nobel-us-5-1	0.38	0.01	0.38	0.00	0.38	0.00	0.38	0.01	0.37	0.01	0.38	0.01
nobel-us-5-2	0.83	0.01	0.84	0.01	0.85	0.02	0.83	0.02	0.84	0.03	0.82	0.05
pdh-3-1	0.29	0.00	0.29	0.00	0.29	0.00	0.29	0.01	0.29	0.01	0.29	0.00
pdh-3-2	0.17	0.01	0.16	0.01	0.15	0.02	0.15	0.02	0.15	0.03	0.16	0.03
pdh-3-3	0.21	0.00	0.21	0.01	0.22	0.02	0.22	0.02	0.23	0.03	0.27	0.05
pdh-4-1	0.35	0.01	0.34	0.01	0.34	0.01	0.34	0.01	0.35	0.01	0.35	0.01
pdh-4-2	0.17	0.01	0.17	0.02	0.19	0.03	0.18	0.03	0.19	0.04	0.21	0.05
pdh-4-3	0.27	0.01	0.28	0.02	0.28	0.02	0.29	0.03	0.31	0.05	0.30	0.05
pdh-5-1	0.41	0.01	0.42	0.01	0.42	0.01	0.42	0.01	0.42	0.01	0.42	0.01
pdh-5-2	0.22	0.01	0.23	0.03	0.25	0.03	0.26	0.05	0.26	0.08	0.26	0.06
pdh-5-3	0.37	0.01	0.36	0.03	0.35	0.03	0.37	0.05	0.43	0.07	0.45	0.09
polska-4-1	0.19	0.00	0.19	0.01	0.19	0.01	0.19	0.00	0.19	0.00	0.19	0.01
polska-5-1	0.39	0.01	0.39	0.01	0.39	0.01	0.39	0.01	0.40	0.01	0.39	0.00
polska-5-2	0.54	0.01	0.54	0.01	0.54	0.01	0.53	0.01	0.53	0.02	0.49	0.04

Table A.80: Time consumation (s) for edge-disjointness on SNDlib instances.

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