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Proof of NP-Hardness, New Mathematical Formulation and Constructive Heuristic for In-band Network Monitoring Optimization

Work presented in partial fulfillment
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ABSTRACT

The increasing usage of distributed and cloud-driven network ecosystems have rendered legacy network monitoring obsolete, as they are unable to provide granular visibility to huge amounts of network traffic data exchanged each day. In-Band Network Telemetry (INT) is showing itself to be a promising alternative to these legacy solutions, by allowing active packets to report their metrics within the network system. This new approach can provide the much needed accurate real-time granular network monitoring solution, yet it may cause network performance degradation if applied aimlessly. Work has been done to formalize an optimization problem, namely the Network Monitoring Optimization problem (NEMO), in the search to find an optimum way for a network to report its current state using INT. We build on top of that work. We introduce a generalization of NEMO and proof that such problem is NP-Hard. Then, we propose a new mathematical formulation and a heuristic algorithm for the problem. In our experiments using real-world network configurations, we observed that the proposed heuristic was able to find high-quality solutions to all networks under 1.7 seconds.

Keywords: Computer Networks. In-band Network Telemetry. Combinatorial Optimization. Heuristics.

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LIST OF ABBREVIATIONS AND ACRONYMS

INT	In-Band Network Telemetry
NEMO	Network Monitoring Optimization Problem
ACDLT	Arcs Covering by Disjoint Limited Trails Problem
X3C	Exact Cover by 3-Sets Problem
MEC	Minimum Exact Cover Problem
MSC	Minimum Set Cover Problem

CONTENTS

1 INTRODUCTION

Monitoring is a key component of network management. Traditional network performance monitoring tools give insight to administrators into the current state of a network, identifying sources of errors and traffic abnormalities, providing actionable information so correct mitigation efforts could be taken to stabilize the network back to a normal state.

Network administrators have a great set of challenges to overcome, and they must rely on monitoring solutions to aid them in this task. One such challenge is the lack of network visibility, because if a portion of a network is invisible, it is impossible to fully understand the network performance at any given time. There is also a need to establish network performance baselines to understand how the network typically performs, in order to properly anomalies in the network. Monitoring solutions must assess New configurations in the network in order to possibly identify a negative impact in the network performance and also must provide rich information so network administrators can plan the network growth driven by data.

Modern distributed and cloud-driven network architectures generate an increasing amount of network traffic worldwide each day. Traditional monitoring solutions are no longer able to meet the demand of granular visibility of such networks, because these tools were no developed with these requirements in mind. The high cost of network downtime corroborates the need for better approaches to monitor an active network and to diagnose anomalies in real-time.

In-Band Network Telemetry (INT) (BROCKNERS et al., 2019) emerges as a viable alternative, being able to provide real-time telemetry reports within the network, although its indiscriminate use could cause network degradation (MARQUES; GASPARY, 2018), mainly due to the increased size of packets with embedded telemetry headers, limited processing capacity of forwarding devices and limited network bandwidth. The development of optimization-based techniques that minimize the impact of INT, could be an interesting approach to avoid the effect of network degradation.

To the best of our knowledge, the first to study the aspects of monitoring a network using INT was (SPANIOL, 2018). They formulated the Network Monitoring Optimization problem (NEMO) and proposed a mathematical model to solve the problem of selecting an optimum telemetry configuration, that comprises the least amount of telemetry reporting from the network devices, while still monitoring the whole network, minimizing the impact that active real-time monitoring causes. Subsequently (MARQUES et al., 2019) proposed a similar optimization-based approach to solve the problem, with two distinct formulations that focus on specific aspects of the problem: one that concentrates the telemetry load among few larger flows, and another that tries to spread the load between more numerous but short flows.

This paper continues (SPANIOL, 2018) by presenting a generalization of NEMO, a new mathematical formulation, a proof of NP-hardness for the problem and a polynomial time heuristic capable of producing high-quality solutions for instances of NEMO.

This work is organized as follows. In Chapter 2, we introduce the Network Optimization problem (NEMO) along with a generalization of the problem and the formalization of two optimization models, then we present a proof of NP-Hardness of the generalization and finally a reduction to the Minimum 3-Exact Cover problem (MEC). In Chapter 3 we propose a heuristic algorithm. In Chapter 4 we evaluate the proposed heuristic and trace comparisons to the optimization model proposed in (SPANIOL, 2018). In Chapter 5 we present our concluding remarks.

2 NETWORK MONITORING OPTIMIZATION PROBLEM

INT uses production traffic to monitor a network, thus we must consider important constraints when orchestrating a monitoring strategy to avoid network degradation (MARQUES et al., 2019). A key constraint is that the packet size cannot exceed the network maximum transmission unit, limiting how much telemetry data we can embed in packet and the number of interfaces that can be monitored. By embedding telemetry data into packets we increase their total size, causing increased levels of jitter, which in turn leads to packet discard and overall degradation of services. Also, the network being monitored has limited bandwidth, and if we embed too many telemetry data into the packets, the high amount of traffic data may also saturate the whole network.

To completely monitor a network using INT, each active packet flow in the network must collect telemetry headers from each interface in its flow and, at the end of the flow, dispatch the telemetry information to a monitoring sink. Each interface in the network has a monitoring demand, that is, each interface has telemetry headers that must be collected by some active flow in the network. To meet the monitoring demand of each interface, a monitoring strategy must choose which active flow collects which telemetry header from a specific interface.

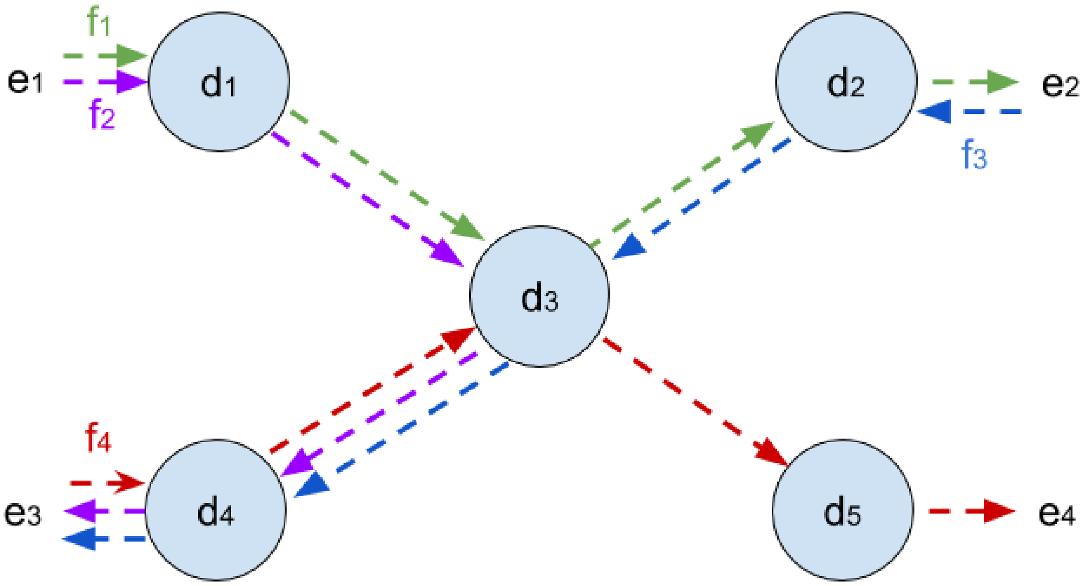
The Network Monitoring Optimization problem (NEMO) consists of selecting a monitoring strategy for a particular network in a way that meets all the monitoring demands while minimizing the telemetry overhead. We start by detailing the inputs and outputs of the problem.

The NEMO is comprised of a physical network infrastructure $G = (D, I)$, a set F of active network flows and a natural k. D is a set of programmable forwarding devices, I is a set of interfaces which are ordered pairs connecting one device to another. Each element of the set F represents an active flow of traffic between two endpoints in the network. Every flow $f \in F$ is a path of device interfaces from the network infrastructure G. For example, a flow f_1 with endpoints s and t, sending traffic through programmable devices $d_1, d_2, d_3 \in D$ is represented by the sequence of interfaces $(s, d_1), (d_1, d_2), (d_2, d_3), (d_3, t)$, in which every interface belongs to the set I. In real scenarios, the devices in the network are connected two-way to one another, but the NEMO problem is only interested in the device interfaces with active traffic flow, so we ignore those interfaces in which no flow $f \in F$ routes through them. The last input is the sub-flow capacity k, which constraints the number of interfaces from which a sub-flow may collect telemetry items which will later dispatched to monitoring sinks at the last device of the sub-flow.

The output to the problem is a set S of flows of G, such that each interface in I is covered by exactly one flow in S, each route in S has length no longer than k and each route in S is a sub-flow of at least one flow in F. The goal of the problem is to minimize the cardinality of the set S.

Figure 2.1 shows an example instance of the NEMO problem with 5 forwarding devices d_1, d_2, d_3, d_4, d_5 and 4 flows $f_1 =$ '$(e_1, d_1), (d_1, d_3), (d_3, d_2), (d_2, e_2)$', $f_2 =$ '$(e_1, d_1), (d_1, d_3), (d_3, d_4), (d_4, e_3)$', $f_3 =$ '$(e_2, d_2), (d_2, d_3), (d_3, d_4), (d_4, e_3)$' and $f_4 =$ '$(e_3, d_4), (d_4, d_3), (d_3, d_5), (d_5, e_5)$'. For capacity $k = 4$, one optimum solution is $s_1 =$ '$(e_1, d_1), (d_1, d_3), (d_3, d_2), (d_2, e_2)$', $s_2 =$ '$(e_2, d_2), (d_2, d_3), (d_3, d_4), (d_4, e_3)$' and $s_3 =$ '$(e_3, d_4), (d_4, d_3), (d_3, d_5), (d_5, e_4)$'.

Figure 2.1: Example instance of the NEMO problem



Source: based on the example presented in (MARQUES et al., 2019)

Next sections will show formal models and definitions for NEMO.

2.1 Graph Representation of NEMO

Graphs are are mathematical structures used to model pairwise relations between objects, in that sense we can formally define NEMO as a graph problem. First, we define the concept of graph we use in this document:

Definition 1. *A* ***directed graph*** *or* ***digraph*** G *is defined by the pair* (V, A)*, where* V *is a non-empty set of elements (denoted by nodes) and* A *is a set of ordered pairs of different nodes (denoted by arcs), i.e.* $A \subseteq V \times V \setminus \{\langle v, v\rangle\}_{v\in V}$.

Obviously we can represent each forwarding device of NEMO by a node and each interface between two devices by an arc between the respective nodes. To represent the active flows we use the definition of trails and paths:

Definition 2. *Given a directed graph* $G = (V, A)$ *and a sequence of nodes* $t = u_1 \cdots u_k$ *(*$u_i \in V,\ 1 \leq i \leq k$*), we say that* t *is a* ***trail*** *iff for all* $1 \leq i < k$*,* $\langle u_i, u_{i+1}\rangle$ *is an arc of* G *(i.e.* $\langle u_i, u_{i+1}\rangle \in A$*) and no arc is repeated in* t*. If the trail* t *do not repeat nodes, then* t *is a* ***path****. We also may represent the trail* t *by the sequence of its arcs instead the sequence of its nodes, being the* ***length*** *of* t *the number of its arcs.*

Definition 3. *Given a trail* $t = u_1, \cdots, u_k$ *in a directed graph* $G = (V, A)$*, a sequence of nodes* $s = v_1 \cdots v_l$ *is a* ***sub-trail*** *of* t *iff* s *is a subsequence of* t*, i.e. exists* $1 \leq j \leq k - l$*, such that for all* $1 \leq i \leq l$*,* $s_i = u_{j+i}$*. If the trail* t *is a path, then* s *is a* ***sub-path*** *of* t*.*

Finally, to indicate that a flow covers an interface and that interfaces must be covered by only one flow, we use the following definitions:

Definition 4. *A trail in a directed graph* $G = (V, A)$ *is said to* ***cover*** *an arc* $a \in A$ *when* a *is contained in the sequence of arcs of the trail.*

Definition 5. *Given the trails* s *and* t *in a directed graph* $G = (V, A)$*, we say* s *and* t *are disjoint iff the intersection of the arcs of* s *and* t *is empty (i.e.* $s \cap t = \varnothing$*).*

Notice that an instance of NEMO receives a directed graph (the network), a set of paths (the active flows) and an integer (the flows capacity), being the objective to find a set of disjoint sub-paths with minimum cardinality that covers each arc of the graph, while guaranteeing that the length of each sub-path does not exceed the flows capacity. The next problem is a generalization for NEMO. Instead of a set of directed paths, the problem considers a set of directed trails and the solution, instead of a set of disjoint sub-paths, is a set of disjoint sub-trails.

Problem 1. *Arcs Covering by Disjoint Limited Trails problem (ACDLT)*

Input: *A tuple* $\langle G = (V, A), F, k\rangle$*, where:*

- $G = (V, A)$ *is a directed simple graph where* V *is the set of nodes and* A *the set of arcs.*

- *F is a set of directed trails of G, which union covers all the arcs of G.*
- *k is an integer.*

Output: *A set S of trails of G, with minimum cardinality such that each arc of G is covered by exactly one trail in S, each trail of S has size at most k and each trail of S is a sub-trail of at least one trail of F.*

2.2 Optimization Models

In order to facilitate the comprehension of NEMO, an integer linear program is presented, previously formulated as the *Cover model* in (SPANIOL, 2018).

For each arc $a \in A$ and path $f \in F$, were defined the binary variables:

$$x_{af} = \begin{cases} 1, & \text{if } a \text{ is covered by } f \text{ in a solution} \\ 0, & \text{otherwise} \end{cases}$$

$$y_{fu} = \begin{cases} 1, & \text{if } f \text{ dispatches at node } u \text{ in a solution} \\ 0, & \text{otherwise} \end{cases}$$

$$c_{fu} = \text{Amount of telemetry items carried by } f \text{ when arriving at node } u.$$

Additionally, the set L was defined containing the last arc from each path $f \in F$.

$$\textbf{min} \sum_{f \in F} \sum_{u \in V} y_{fu} \tag{2.1}$$

$$\textbf{s.t.} \sum_{f \in F} x_{af} = 1 \qquad \forall a \in A \tag{2.2}$$

$$x_{af} = 0 \qquad \forall a \in A \backslash f, \forall f \in F \tag{2.3}$$

$$x_{af} \geq y_{fu} \qquad \forall f \in F, \forall a = (u, v) \in A \tag{2.4}$$

$$x_{af} * k \geq c_{fu} \qquad \forall f \in F, \forall a = (u, v) \in A \tag{2.5}$$

$$y_{fu} - x_{af} \geq -c_{fv} \qquad \forall f \in F, \forall a = (u, v) \in A \tag{2.6}$$

$$(-y_{fu} + x_{af}) * k \geq c_{fv} \qquad \forall f \in F, \forall a = (u, v) \in A \tag{2.7}$$

$$c_{fv} \leq cfu + 1 + (1 - x_{af}) * k + y_{fu} * k \qquad \forall f \in F, \forall a = (u, v) \in A \tag{2.8}$$

$$c_{fv} \geq cfu + 1 - (1 - x_{af}) * k - y_{fu} * k \qquad \forall f \in F, \forall a = (u, v) \in A \tag{2.9}$$

$$y_{fu \geq x_{af}} \qquad \forall f \in F, \forall a = (u, v) \in L \tag{2.10}$$

$$c_{fu} \in \mathcal{Z}^{+} \qquad \forall f \in F, \forall u \in V \tag{2.11}$$

$$x_{af} \in \{0, 1\} \qquad \forall f \in F, \forall a \in A \tag{2.12}$$

$$y_{fu} \in \{0, 1\} \qquad \forall f \in F, \forall u \in V \tag{2.13}$$

The objective function 2.1 defines the minimization of telemetry item packet dispatches by the sum of the y variables. Constraint set 2.2 ensures that every arc $a \in A$ is covered by some trail $f \in F$. Constraint set 2.3 limits that a trail $f \in F$ can cover an arc $a \in A$ only if the arc is part of its path. Constraint set 2.4 ensures that a trail $f \in F$ can only dispatch at node $u \in V$ if it collects the telemetry item from the arc $a \in A$. Constraint set 2.5 defines that if a trail $f \in F$ is not collecting an item at the arc $a \in A$, then the trail's load at the node $u \in V$ is 0. Constraint set 2.6 ensures that if a trail $f \in F$ covers arc $a \in A$ and does not dispatch at node $u \in V$, then its load must be greater than 0. Constraint set 2.7 limits the maximum load of any trail $f \in F$. Constraint sets 2.8 and 2.9 define that if a trail $f \in F$ does not dispatch at node $u \in V$ and covers arc $\langle u, v \rangle$, then the load of the given trail f at the node $v \in V$ is equal to the load of the trail f at the node u plus 1. Constraint set 2.10 requires that if a trail collects a telemetry item at its last arc, then it also dispatches at that arc.

The constraint set 2.11 defines the domain of the variable c_{fu}, which is positive integer. Constraint sets 2.12 and 2.13 define the domain of the variables x_{af} and y_{fu}, which are binary.

The presented model works when the set F contains only simple paths, however the model does not solve the problem when we allow general trails, since the goal is to minimize the number of dispatch nodes by path. If a path has repeated nodes, it may be broken at the same node several times and it will not sum up in the objective function.

For this reason, we propose a new model that allows general trails. Consider we break each trail $f \in F$ into every possible sub-trail of size at most k, then S is the set of these sub-trails. Since a trail in F has at most $|A|$ arcs, this operation produces for each trail $f \in F$ at most $\sum_{i=0}^{k-1} |A| - i$ sub-trails, implying the operation is polynomial ($\mathcal{O}(|F| \cdot |A| \cdot k)$).

For each arc $a \in A$ and sub-trail $s \in S$, we define the binary variables:

$$x_{as} = \begin{cases} 1, & \text{if } a \text{ is covered by sub-trail } s \text{ in a solution} \\ 0, & \text{otherwise} \end{cases}$$

$$y_s = \begin{cases} 1, & \text{if sub-trail } s \text{ is in a solution} \\ 0, & \text{otherwise} \end{cases}$$

Additionally, we define $S(a)$ as the subset of S with the trails containing the arc a. Then, our model results:

$$\mathbf{min} \sum_{s \in S} y_s \tag{2.14}$$

$$\mathbf{s.t.} \sum_{s \in S(a)} x_{as} = 1 \qquad \forall a \in A \tag{2.15}$$

$$\sum_{a \in s} x_{as} = |s| y_s \qquad \forall s \in S \tag{2.16}$$

$$x_{as} \in \{0, 1\} \qquad \forall a \in A, \forall s \in S \tag{2.17}$$

$$y_s \in \{0, 1\} \qquad \forall s \in S \tag{2.18}$$

The objective function 2.14 defines the minimization of the selected sub-trails by the sum of the y variables. Constraint set 2.15 ensures that every arc $a \in A$ is covered by some sub-trail $s \in S(a)$. Constraint set 2.16 ensures that if a trail $s \in S$ is selected to the solution, then it must cover all of its arcs, and also ensures that if an arc is covered by a trail, then such trail must be selected to the solution. Constraint sets 2.17 and 2.18 define the domain of the variables x_{as} and y_s, which are binary.

Our model is not only more general than the one presented by (SPANIOL, 2018), but also all the variables are binary, which allows the use of specialized techniques for solving binary integer programs, such as the Balas Additive Algorithm (BALAS, 1965).

2.3 Proof of NP-Hardness

In this section, we prove that ACDLT is NP-Hard by a polynomial reduction from the 3-Exact Cover problem (X3C), a classic NP-Complete problem (JOHNSON; GAREY, 1979). First, we define the X3C:

Problem 2. *3-Exact Cover problem (X3C)*

Input: *A tuple $\langle X, C\rangle$, where:*

- *X is a finite set of elements with cardinality $3q$, for some natural q (i.e. the number of elements is a multiple of 3).*
- *C is a collection of triples of X (i.e. 3-element subsets of X).*

Output: *A sub-collection C^* of C, such that the intersection of any two distinct triples of C^* is empty and the union of the triples of C^* is X.*

Now, we are able to prove the following theorem:

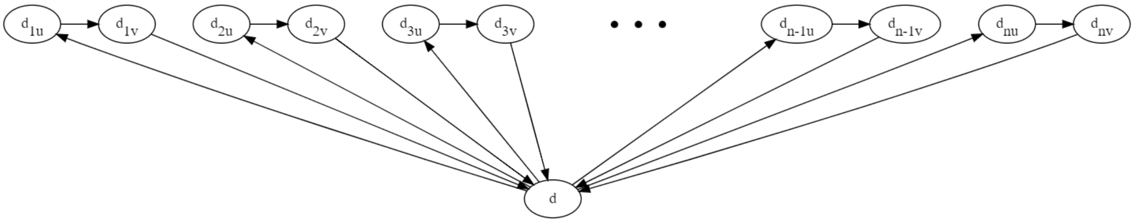
Theorem 1. *ACDLT is NP-Hard.*

Proof. Given an instance of X3C (X, C), we reduce to an instance (G, F, k) of ACDLT as follows.

First, we construct a directed graph G with a single node $d \in V$, used as a central point for all arcs in the graph. Then, for each element $x \in X$, we define 2 nodes $d_{xu}, d_{xv} \in V$ and 3 arcs $a_{xj}, a_{xk}, a_{xl} \in A$. The first arc connects the central node d to the node d_{xu}, the next arc connects the node d_{xu} to the node d_{xv}, and the final arc connects the node d_{xv} to the central node d, forming a cycle. Figure 2.2 shows the graph constructed by the reduction algorithm for an instance of the X3C where the set X has n elements $X = \{1, 2, 3, \ldots, n-1, n\}$.

Next, we construct the set F of trails in the graph G. For every triple $c = \{x, y, z\} \in C, x, y, z \in X$, we define a trail $f \in F$ with the following arcs: (d, d_{xu}), (d_{xu}, d_{xv}), (d_{xv}, d), (d, d_{yu}), (d_{yu}, d_{yv}), (d_{yv}, d), (d, d_{zu}), (d_{zu}, d_{zv}), (d_{zv}, d). Each trail

Figure 2.2: Example graph constructed by reduction from X3C to ACDLT



Source: Author

starts at the central node d, then it passes through every group of 3 arcs representing each element in the set, ending at the central node d. Since every trail $f \in F$ has length 9, we set the maximum trail length $k = 9$.

Now, we prove that there exists a solution for X3C iff an optimal solution for ACDLT has cardinality $\frac{n}{3}$.

Suppose there is a sub-collection C^* of C that is an exact cover of X, we construct the set $S^* \subseteq F$ by selecting the trails corresponding to each triple $c \in C^*$. Since C^* is an exact cover, all the elements of X are covered by C^*, implying that the 3-arc defined for each element of X are covered by S^*, so S^* covers all the arcs of A. Also, the triples of C^* have no common elements, so the trails of S^* are disjoint. Finally, notice that each element in S^* has exactly 9 arcs, so the cardinality of S^* must be $\frac{n}{3}$ to cover the $3n$ arcs of A. Therefore, if there exists an exact cover C^* for an instance of X3C, then there exists a $\frac{n}{3}$ cardinality set S^* of disjoint trails with length at most 9 that covers A.

In the other way, consider there exists a $\frac{n}{3}$ cardinality set S^* of disjoint trails that covers A, where each trail has length at most 9. Suppose there also exists a trail $s \in S^*$ that covers some arcs of some element $x \in X$, but not all 3-arcs associated to that element (the trail s partially covers x). Since s is a sub-trail of some trail $t \in S$ with cardinality 9 that covers exactly 3 elements of X, s can acquire one more arc associated with the element x, without exceeding the length of 9. Such arc must be covered by another sub-trail of S^* that ends at that arc being adjacent to s. So, when the trail s takes the last arc of the element x from an adjacent sub-trail, we are simply changing the arc from one trail to another, without increasing the cardinality of S^*. If after that operation, the trail still needs another arc to cover all 3 arcs associated to x, we repeat the process.

Then, we can then construct a set S' with the same cardinality of S^* that is a solution for ACDLT, ensuring that there are no trails in S' that partially covers some element of X, i.e. if a trail $s' \in S'$ covers some arc associated to any element $x \in X$, then s' covers all 3-arcs associated to x. We say that a trail covers an element $x \in X$ if the trail covers all 3-arcs associated to the element x.

Since S' is a solution with no trail partially covering some element of X, the trails of S' must cover one, two or three elements of X. Let k_1 be the number of trails in S' that cover one element of X, let k_2 be the number of trails in S' that cover two elements of X, and finally let k_3 be the number of trails in S' that cover three elements of X. The sum of the elements covered by all trails in S' must be equal to n, the cardinality of the set X. Therefore the following equation must be true:

$$k_1 + 2k_2 + 3k_3 = n \tag{2.19}$$

The cardinality of the set S' must be $\frac{n}{3}$, thus the sum of all trails that cover one, two and three elements mus be equal to $\frac{n}{3}$:

$$k_1 + k_2 + k_3 = \frac{n}{3} \tag{2.20}$$

Equations 2.19 and 2.20 hold true only if $k_1 = 0$ and $k_2 = 0$. Consequently, the set S' has only full trails of F covering 9 arcs of A, with each trail corresponding to one triple in C. Then, by selecting the corresponding triples from S' to C^*, we obtain a collection of disjoint triples that covers all the elements of X, i.e. C^* is an exact cover for the corresponding instance of X3C.

□

2.4 Approximation-Preserving Reduction from ACDLT to Minimum Exact Cover Problem

In this section, we show that every instance of the ACDLT can be reduced to an instance of the Minimum Exact Cover problem (MEC) preserving the approximability features. First, we define some concepts regarding α-approximation:

Definition 6. *Given a minimization problem* Π*, a value* $\alpha > 0$ *and an algorithm* A *for* Π*, we say that* A ***α-approximates*** Π *iff for every instance* I *of* Π*,* A *finds a solution that is at most* $\alpha \times OPT_I$*, being* OPT_I *the value of an optimal solution for* I*.*

Definition 7. *Given two minimization problems* Π *and* Π'*, two polynomial computable functions* (z, p) *and two positive constants* α *and* β*, we say that* (z, p) *is an* ***approximation-preserving reduction*** *iff for every instance* I *of* Π*,* $z(I)$ *is an instance* I' *of* Π'*, for every* *solution y of z(I), $p(y)$ is a solution to the original instance I, y is at most $\alpha \times OPT_{z(I)}$ and $p(y)$ is at most $\beta \times OPT_I$.*

Now, we define the MEC:

Problem 3. *Minimum Exact Cover problem (MEC)*

Input: *A tuple $\langle X, C\rangle$, where:*

- *X is a finite set of elements.*
- *C is a collection of subsets of X.*

Output: *A sub-collection C^* of C, with minimum cardinality such that the intersection of any two distinct subsets of C^* is empty and that the union of the subsets in C^* is X.*

The following theorem proves that ACDLT is not harder than MEC:

Theorem 2. *There exists an approximation-preserving reduction (z, p, α, β) from ACDLT to MEC.*

Proof. Given an instance $\langle G = (V, A), F, k\rangle$ of the ACDLT, we reduce it to an instance $\langle X, C\rangle$ of MEC as follows.

Define the set of elements of MEC equals to the set of arcs of ACDLT, i.e. $X = A$ and, for each trail $f \in F$ generate every possible sub-trail of f with length less or equals to k. Define C as the collection containing all the sub-trails generated, which are subsets of X. Since a trail in F has at most $|A|$ arcs, the reduction algorithm produces for each trail $f \in F$ at most $\sum_{i=0}^{k-1} |A| - i$ sub-trails, implying the reduction algorithm is polynomial ($\mathcal{O}(|F| \cdot |A| \cdot k)$). (This polynomial algorithm is the function z which transforms an instance from ACDLT to MEC).

For example, consider an instance of the ACDLT with a set $A = \{a_1, a_2, a_3, a_4\}$, a set F containing only the single trail $f_1 =$ ‘a_1, a_2, a_3, a_4’ and $k = 3$, then the reduction to an instance of the MEC will produce the set $X = \{a_1, a_2, a_3, a_4\}$ and the collection of subsets $C = \{\{a_1\}, \{a_2\}, \{a_3\}, \{a_4\}, \{a_1, a_2\}, \{a_2, a_3\}, \{a_3, a_4\}, \{a_1, a_2, a_3\}, \{a_2, a_3, a_4\}\}$.

Every subset of C produced by the reduction is a valid sub-trail of some trail $f \in F$, hence any sub-collection C^* of C only contains subsets that are valid sub-trail of some trail $f \in F$. Also, any feasible sub-collection C^* must be compound of disjoint elements and the union of the subsets must be X, so C^* relates to a solution S^* of the instance of the original ACDLT problem, with every subset of C^* relating to a sub-trail of its respective trail in F. Even more, both solutions C^* and S^* have same cardinality. (This polynomial algorithm is the function p that transforms a solution of the reduced instance of MEC to a solution of the original instance of ACDLT).

In the other way, if there exists a feasible solution S^* for an instance of the ACDLT, then each sub-trail $s \in S^*$ relates to a subset $c \in C$ of the reduced instance of the MEC, forming a sub-collection of subsets C^* with same cardinality than S^*. Since S^* is feasible, then its sub-trails are disjoint and cover all A, so C^* is an exact cover for the constructed instance of MEC. Therefore, any feasible solution S^* of ACDLT corresponds to a feasible solution C^* for the constructed instance of MEC with the same cardinality.

Since every feasible solution S^* of the ACDLT can be transformed in a feasible solution C^* of the MEC with same cardinality and vice-versa, the optimum value is the same for both problems. If a solution C^* for the reduced instance of the MEC α-approximates the optimum value, then the related solution S^* of the ACDLT also α-approximates the optimum value ($\alpha = \beta$).

$\square$

From the above reduction, we conclude that any algorithm that α-approximates MEC also α-approximates ACDLT. This could help to solve any instance of ACDLT by using any approach for MEC. We present this result as a corollary:

Corollary 1. *For any α, an algorithm that α-approximates MEC also α-approximates ACDLT.*

The approximation-preserving reduction from the ACDLT to the MEC implies that the ACDLT is approximable within equal factor as the approximation results for the MEC, but does not imply that there are no better results for the ACDLT. We did not find approximation or inapproximability results for either MEC or ACDLT in the literature, therefore these results are still open.

3 CONSTRUCTIVE HEURISTIC FOR ACDLT

In this chapter, we propose a polynomial time heuristic algorithm for ACDLT. The heuristic first sorts the trails according to a certain criterion, then, analyzes each trail (in order), deciding whether the trail should be cut into sub-trails or whether a previously selected trail should be discarded in favor of a new one that fully contains the discarded trail. Algorithm 1 shows our heuristic, which we describe in the sequence.

Algorithm 1 NEMO heuristic pseudocode

```
Requires: $A, F, k$
S $\leftarrow \varnothing$
$c \leftarrow 0$
CoveredBy$(a) \leftarrow$ Null, $\forall a \in A$
UFs $\leftarrow$ SORT$(f \in F, |f|, -\sum_{a \in f} |\text{FLOWS}(a)|)$
for $f \in$ UFs do
    $h \leftarrow 0$
    $t \leftarrow 0$
    while $t < |f|$ do
        $g \leftarrow$ CoveredBy$(f(t))$
        if $g =$ Null then
            $t \leftarrow t + 1$
        else if SUBTRAIL(S$(g), f$) then
            $t \leftarrow t + |\text{S}(g)|$
            S$(g) \leftarrow$ Null
        else if $|f(h : t)| > 0$ then
            S $\leftarrow$ S $\cup f(h : t)$
            for $a \in f(h : t)$ do
                CoveredBy$(a) \leftarrow c$
            $c \leftarrow c + 1$
            $h \leftarrow t$
        else
            $h \leftarrow h + 1$
            $t \leftarrow h$
    if $|f(h : t)| > 0$ then
        S $\leftarrow$ S $\cup f(h : t)$
        for $a \in f(h : t)$ do
            CoveredBy$(a) \leftarrow c$
        $c \leftarrow c + 1$
R $\leftarrow \varnothing$
for $s \in S$ do
    for $a \leftarrow 0, k, 2k, 3k, ..., |s|$ do
        R $\leftarrow$ R $\cup\, s(a : min(a + k, |s|))$
return R
```

The algorithm requires three inputs: the set A of arcs, the set F of trails and the sub-trail capacity k. The main variables of the algorithm are the solution set S of all selected sub-trails and the index c, which indicates the number of trails being selected to the solution by the algorithm. At the start there are no solutions, so Lines 1-2 initialize S and c to correspond this.

There are two other auxiliary structures in the main scope of the algorithm: CoveredBy (Line 3) and UFs (Line 4). The structure CoveredBy is indexed on the arcs and indicates which sub-trail $s \in S$ covers each arc $a \in A$. At the beginning CoveredBy is none for all arcs (Line 3). The structure UFs contains the elements of F sorted in ascending order by the length of each trail and, in case of ties, in descending order by the sum of the number of trails covering the arcs of each trail (Line 4).

Lines 5-28 contains the main loop of the algorithm, in which it iterates through each trail $f \in$ UFs to decide whether the trail (or parts of it) should be included in the solution. On each iteration, there are two variables h and t, with initial values equal to 0 (Lines 6-7), which are indexes to the head and tail, respectively, of a slice of the current trail $f \in$ UFs. A slice of some trail $f \in F$ with head index h and tail index t is represented by $f(h : t)$. Notice that, for some trail $f =$ '$a_1, a_2, ..., a_l$' if $0 \leq h \leq t \leq l$, the slice $f(h : t)$ contains the arcs '$a_{h+1}, a_{h+2}, ..., a_{t-1}, a_t$' and if $h = t$, then the slice $f(h : t)$ is empty ($f(h : h) = f(t : t) = \varnothing$). Such slice represents the sub-trail considered to be included in the solution, which expands or shrinks as it traverses the current trail.

The slices of the current trail are selected to the solution by changing the values of h and t in the loop between Lines 8-23. First, on Line 9, the auxiliary variable g receives the sub-trail index that covers the arc $f(t)$ on the solution (which is the current arc of f being analyzed). If the arc is not covered by the solution being constructed (Line 10), then we expand the current slice of f with the inclusion of the arc (Line 11). In case the arc is covered by a sub-trail of the current trail f (Line 12), we also expand the current slice of f with the inclusion of the sub-trail, by adding its length to the tail index t (Line 13) and removing the sub-trail covering the arc, since we will add a larger sub-trail (containing the current slice). The reason of removing obsolete sub-trails covering an arc is that the new sub-trail being constructed by the slice includes more arcs than the previous one, implying that the final solution size could be smaller. That is the main idea of the algorithm, to minimize the number of sub-trails by replacing smaller sub-trails by greater ones while maintaining the already covered arcs.

If the sub-trail covering the current arc in the solution is not a slice of the current trail, then we analyze two possibilities. The first possibility considers the case in which the current slice has positive length. In such case, we include the sub-trail defined by the slice in the solution, indicating that the sub-trail covers all the slice arcs (Lines 15-19) and we shrink the slice by setting its head equals to its tail (Line 20). The other possibility considers an empty slice, in such case we just update the head and the tail to the next position, keeping the slice empty (Lines 22-23).

At the end of the main loop, the Lines 24-28 include in the solution the last slice of the current trail, which was not in the inner loop (for example, when no collisions with an existing sub-trail are found). After the end of the loop between Lines 24-28, we have an output set S with disjoint sub-trails that cover all the arcs $a \in A$, but we have not yet enforced the telemetry capacity constraint on any sub-trail, therefore we split any sub-trail $s \in S$ that exceeds the telemetry capacity k into sub-trails with length at most k and we include them in the set R (Lines 29-32). To conclude, return the set R (Line 33).

Finally, the SUBTRAIL(a, b) procedure on Line 12 evaluates to true when the trail a is a sub-trail of the trail b and evaluates to false otherwise. This procedure can be mapped to a string search algorithm, in which the trails are the strings and the arcs of the trail are the letters making up the string, and the algorithm returns true if it finds the substring a in the string b, and returns false otherwise. Therefore, the SUBTRAIL procedure can be implemented with any well-known string search algorithm, such as the Knuth–Morris–Pratt (KNUTH; MORRIS; PRATT, 1977) or Boyer–Moore (BOYER; MOORE, 1977) algorithms.

Since every instance of the ACDLT guarantees that each arc is covered by at least one trail $f \in F$, then this heuristic is always able to find a feasible solution for every instance of the problem, because it iterates through every trail in the network sequentially, and for each trail, it covers every arc in the trail that has not been already covered by some previous sub-trail.

Line 3 has time complexity $\mathcal{O}(|A|)$. Line 4 has time complexity $\mathcal{O}(|F| \cdot \log |F|)$. Lines 10-23 have time complexity $\mathcal{O}(\max_{f \in F}(|f|))$. Lines 8-23 have time complexity $\mathcal{O}(\max_{f \in F}(|f|)^2)$. Lines 24-28 have time complexity $\mathcal{O}(\max_{f \in F}(|f|))$. Lines 5-28 have time complexity $\mathcal{O}(|F| \cdot \max_{f \in F}(|f|)^2)$. Lines 29-33 have time complexity $\mathcal{O}(|F| \cdot k \cdot \max_{f \in F}(|f|)^2)$. Since for any trail $f \in F$, $|f| \leq |A|$, we conclude the total time complexity of the heuristic is $\mathcal{O}(|A| + |F| \cdot k \cdot max(|f|)^2)$.

3.1 Alternative sorting

In this section, we show an alternate sorting criterion of the trails that can be applied in order to improve the final solution produced by the proposed heuristic. This alternative method tries to exploit the property of network trails that uniquely covers an arc and, therefore, must appear fully or at least partially in the solution.

We say some trail $f \in F$ uniquely covers an arc $a \in A$ iff no other trail in F cover the same arc a. For that reason, the trail f must appear in the solution, otherwise the arc a would not be covered. Given this property, we may sort the trails in such a way that all trails uniquely covering some arc $a \in A$ are processed beforehand.

We replace the sorting method on Line 4 of the Algorithm 1 to first consider the trails that uniquely cover an arc and in case of ties, to follow the sorting criterion described in the previous section.

In order to illustrate the advantages of the new sorting criterion, suppose we have the set $A = \{a_1, a_2, a_3, a_4\}$ and four trails $f_1 =$ 'a_1, a_2', $f_2 =$ 'a_1, a_3', $f_3 =$ 'a_3, a_4' and $f_4 =$ 'a_4'. The trail f_1 uniquely covers the arc a_2. Without this sorting criterion, the selected sub-trails would be $s_1 =$ 'a_4', $s_2 =$ 'a_1, a_3' and $s_3 =$ 'a_2', obtaining a solution with three trails. If we use this sorting method, the heuristic will select the trail f_1 first, because it uniquely covers the arc a_2, and after the heuristic iterates the remaining trails, the final solution will be $s_1 =$ 'a_1, a_2' and $s_2 =$ 'a_3, a_4', obtaining a better solution with two trails.

4 COMPUTATIONAL EXPERIMENTS

In this chapter, we present computational experiments to test our heuristic over the benchmark used by (SPANIOL, 2018). First, we will detail the experiment setup and the dataset used. Next, we will evaluate the heuristic considering the processing time and solution quality, which will be compared with the exact solution of the Cover Model presented in (SPANIOL, 2018).

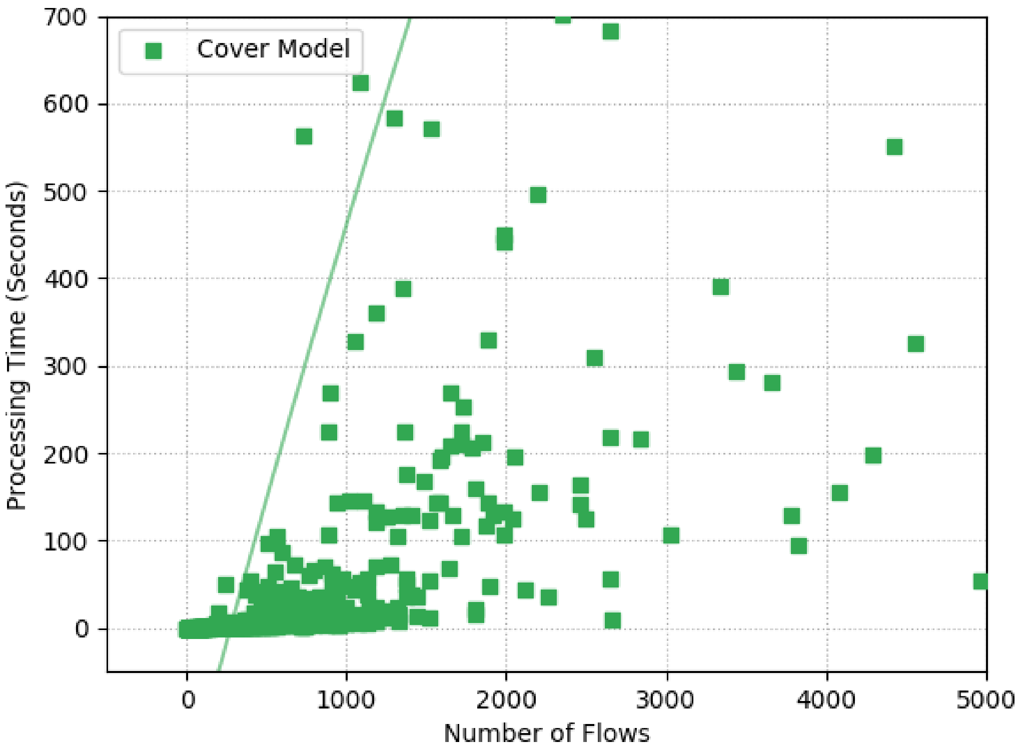
The experiments were conducted in a computer with an Intel Core i7-4790K processor running at 4.00GHz, 16GB of DDR3 1600MHz RAM and Debian GNU/Linux 9.7 operating system. The proposed heuristic was implemented in Python 3.7.3. All the results for the Cover Model were taken from (SPANIOL, 2018), which experiments were run using the CPLEX solver.

For comparison purposes, the dataset used is identical to the one used in (SPANIOL, 2018). The dataset is composed of 119 topologies from the real wide network mapped by the Internet Topology Zoo (KNIGHT et al., 2011). Each topology has five different variations of network activity, totalizing a dataset with 595 network topologies. The network activity is measured by the number of flows in the network. In the first variation, there are 100% of the flows. In the second, third, fourth and fifth variations, there are 80%, 60%, 40% and 20% of the flows, respectively. For all instances, the flow telemetry capacity was set to five ($k = 5$).

We also compare the proposed heuristic to a baseline heuristic that generates random solutions. The baseline heuristic randomly selects an uncovered arc, then randomly selects a trail among the trails that cover the selected arc. Next, the heuristic selects the maximal sub-trail of the selected trail that covers the selected arc and that does not intersect any other already selected sub-trail for the solution. The process is repeated until all the arcs are covered. Finally, if any sub-trail has length greater than k, then the sub-trail is broken into sub-trails with length at most k.

For each network in the dataset, we ran the baseline heuristic 10 times and measured the mean of the results. We used the Python programming language built-in module **random** (RANDOM..., 2019) to generate pseudo-random numbers, using the numbers 1 through 10 as seed in the iterations set with the module's function **seed()** (RANDOM..., 2019). To randomly choose an arc and and then choose a trail that covers the chosen arc, we used the module's function **choice()** (RANDOM..., 2019), which randomly selects an element from a given sequence.

Figure 4.1: Processing time for the optimization model



Source: Adapted from (SPANIOL, 2018)

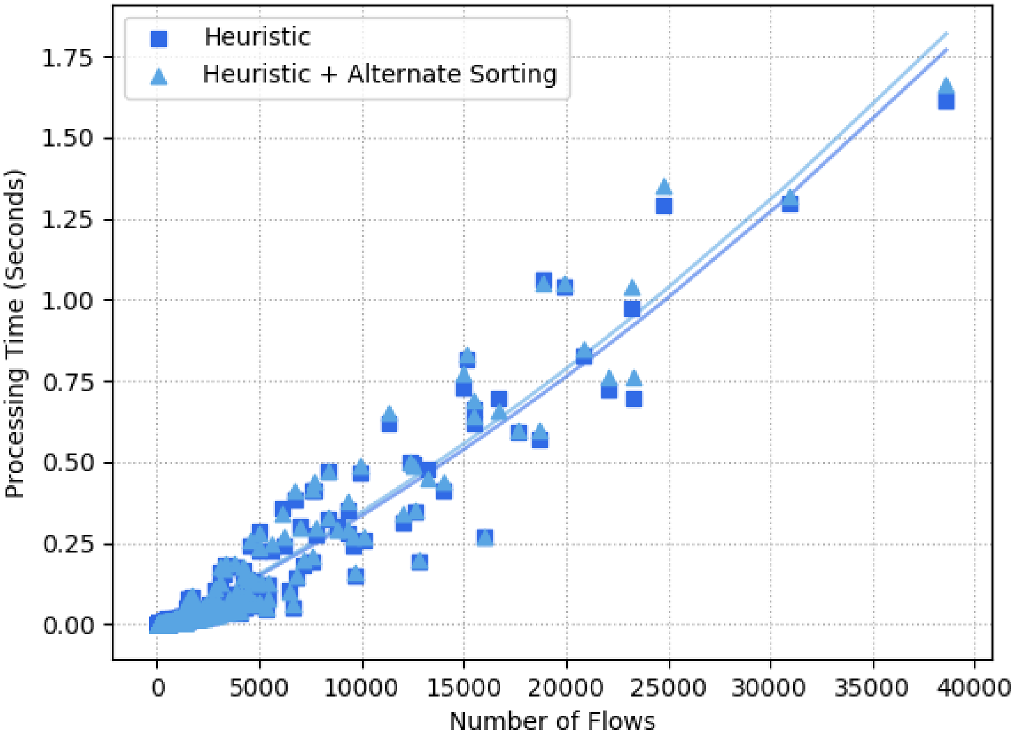
4.1 Time Analysis

To be useful in real-world situations, a procedure to solve any instance of the NEMO problem must be capable of providing high-quality solutions in a short amount of time, given the high rate in which networks experience changes in topology layout, work policies and load across the connected devices.

We first examine the processing time for each method. Figure 4.1 shows the time taken for the CPLEX solver to find a solution for each NEMO instance of the dataset. Figure 4.1 shows data adapted from the results table in (SPANIOL, 2018). The processing grows quickly as the number of flows in the network increases, with the CPLEX solver being unable to find an optimum solution for 82 of the instances within the one-hour time limit. Apart from the number of flows, we observed that other network characteristics such as device and interface count also contributed to an increase in processing time. Therefore, the considerable amount of time taken to find a solution to an instance of the NEMO problem makes the optimization model impractical to apply in real-world settings.

Figure 4.2 shows the running time for the heuristic compared to the number of

Figure 4.2: Processing time for the heuristic



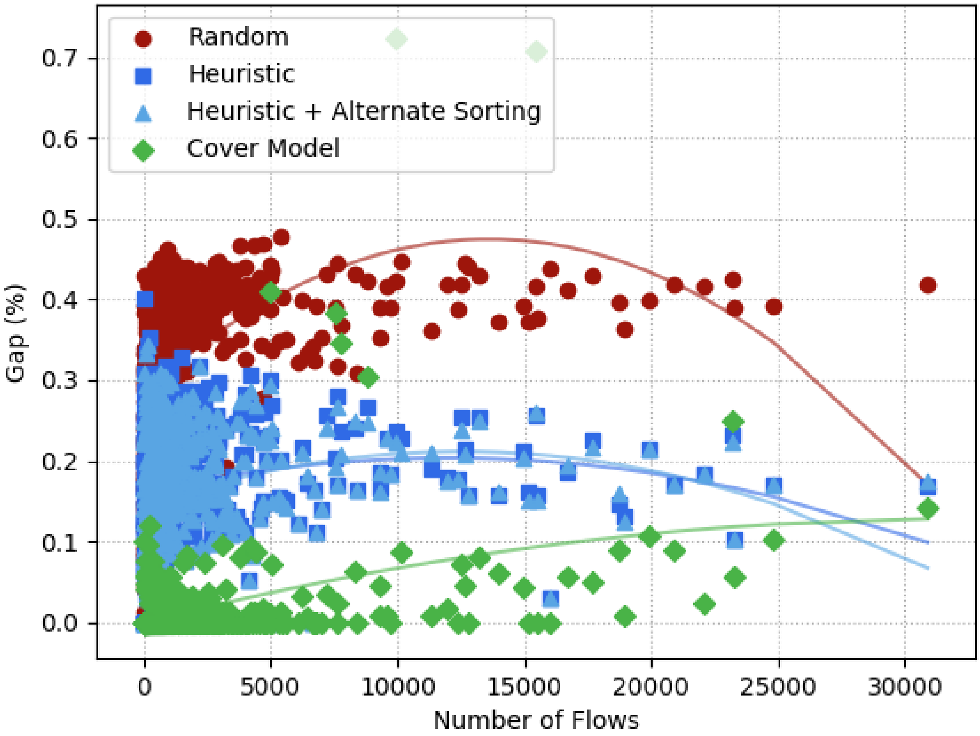
Source: Author

flows in the network. The heuristic was able to find a feasible solution for every instance of the NEMO problem under 1.7 seconds. Running the heuristic with the alternate sorting method applied did not hugely impact the processing time, also finding a feasible solution for every instance of the NEMO problem under 1.7 seconds. These results show that the processing time of the heuristic is up to three orders of magnitude lower than the time required by the optimization model. Given the short amount of time taken to find a feasible solution, the heuristic is a strong candidate to be used in real-world highly dynamic network scenarios. Next, we evaluate the solution quality of both approaches.

4.2 Solution Quality Analysis

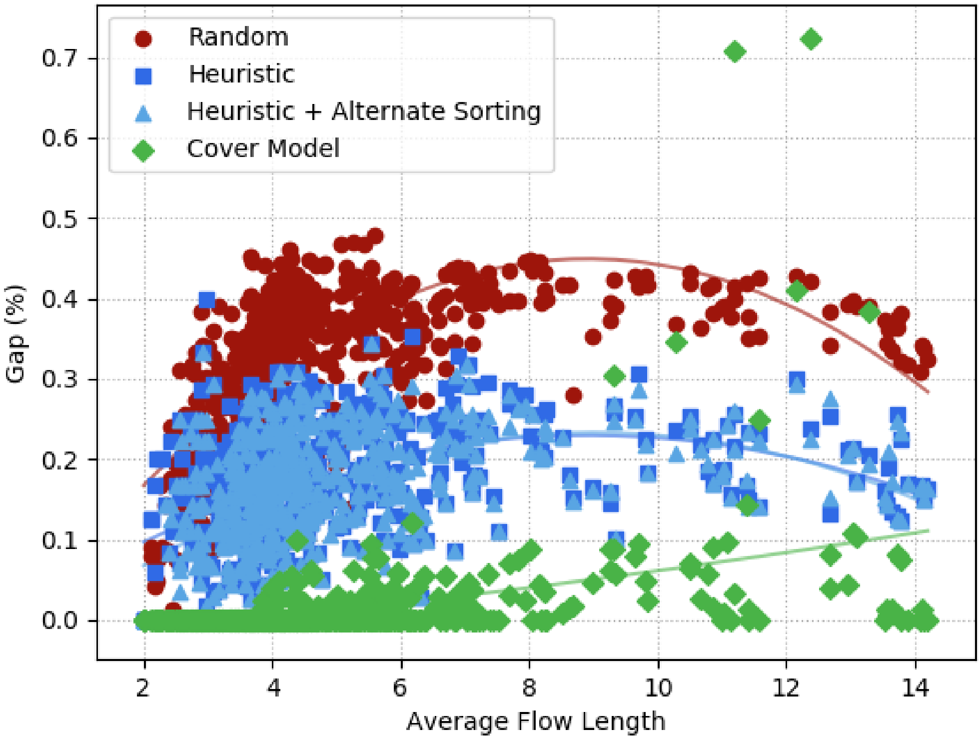
To analyze the solution quality of the optimization model and the heuristic, we compare their objective functions to lower bound models. Figures 4.3 and 4.4 show the solution gap to the lower bound for the optimization model and the heuristic as a function of the number of flows in the network and the average flow length, respectively. A table of all results in this experiment is shown in Appendix 6.1.

Figure 4.3: Gap for the number of flows in the network



Source: Author

Figure 4.4: Gap for the average length of a flow in the network



Source: Author

The mean gap between the lower bound model and the optimization model in which a feasible solution was found by the solver was 13% (with a standard deviation of 5%. The minimum and maximum gaps were 0% and 72%, respectively. The mean gap between the lower bound and the heuristic was 17% (with a standard deviation of 7%). The minimum and maximum gaps were 0% and 40%, respectively. The mean gap between the lower bound and the heuristic with the alternate sorting method applied was 16% (with a standard deviation of 8%). The minimum and maximum gaps were 0% and 36%, respectively. The mean gap between the lower bound and the baseline heuristic was 32% (with a standard deviation of 9%). The minimum and maximum gaps were 0% and 48%, respectively.

Comparing the gaps, we conclude that the solutions provided by the optimization model are better than the ones provided by the heuristic. The heuristic excels for networks with a bigger size, particularly the instances in which the optimization model was unable to find any solution. The maximum gap is also much lower for the heuristic, 40% compared to 72% of the optimization model, and the mean gap is only 5% higher, 17% compared to 13%, thus, the heuristic was able to consistently find solutions within an acceptable difference from the optimization model, with the distinction of being much faster. Compared to the results from the baseline heuristic, overall, our heuristic produces solutions 2 times better.

The alternate sorting method did not cause a significant impact on the results. Although the mean gap and the maximum gap were slightly better compared to running the heuristic without the alternate method (16% compared to 17% and 36% compared to 40%, respectively), the solution is sometimes better and sometimes worse than those produced by the heuristic without the alternate sorting applied, showing that the method lacks any proper consistency in its effectiveness.

We observed that the heuristic tends to produce solutions with larger flows, increasing the overall load on individual flows, instead of balancing the load among several short flows. This behavior is justified by the heuristic preference for larger continuous flows, systematically removing short flows subsumed by larger ones, with the goal of minimizing the amount of sub-flows selected for the solution.

Given the results, we conclude that the heuristic algorithm is suitable to be used in real-world situations, trading off a slight decrease in solution quality with a much shorter amount of time to find a feasible solution, even for the instances that the optimization model was unable to find any. Our heuristic is suitable even in scenarios where the network flows are not fixed, given the fast execution time of the heuristic for networks ranging from small to huge sizes, implying that we can run the heuristic every time the network layout changes without loss of either performance or monitoring coverage.

5 CONCLUSION

This paper continues the work done in (SPANIOL, 2018), which formalized the Network Monitoring Optimization problem (NEMO). We introduced a generalization for NEMO, the Arcs Covering by Disjoint Limited Trails problem (ACDLT) and proved that the problem belongs to the NP-Hard class. Also, we presented a new mathematical model for ACDLT which is also suitable for NEMO and proposed a heuristic to solve instances of the problem in a timely manner.

Through the results of the experiments, we showed that the heuristic was able to provide high-quality solutions under 1.7 seconds for all instances evaluated. Therefore, the heuristic offers a good trade-off between solution quality and processing time, implying that could be used in real-world scenarios in which networks are highly dynamic in configuration and load.

As future work, the heuristic could be adjusted and evaluated against variations of the NEMO problem, such as the INTO Concentrate and the INTO Balance problems proposed in (MARQUES et al., 2019), to explore if there is any gain in time or solution quality. By the same token, we could attempt to develop a meta-heuristic to further decrease the solution gap, with a constraint of maintaining the processing time short, and even use the solution given by the heuristic as a *warm start* for mixed integer program solvers. One other possibility is to apply the new mathematical model to solve NEMO, as well as develop a new algorithm based on this new model. Another direction is to prove the hardness of NEMO itself.

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6 APPENDIX

6.1 Results

Table 6.1 shows the results for each instance of the NEMO problem used in the experiments. For each instance, it is given its name, the number of devices in the network, the number of interfaces, the number of flows and the average flow length. Then the columns are divided into sections for each method applied. The first method is the Lower Bound model, which serves as the base method which we compare the other methods to. Then comes the Cover model, the Heuristic, the Heuristic with alternate sorting applied and the baseline Random Heuristic. For each method, it is shown the solution (Sol), the time taken to find it, and the solution gap to the Lower Bound method. Cells with a dashed line indicate that the method was not able to find a solution in the allotted time.

Table 6.1: Results

Instance Name	$\|D\|$	$\|I\|$	$\|F\|$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_7_3	5	6	3	2.00	3	0.00	3	0.01	0.00	3	0.00	0.00	3	0.00	0.00	3.0	0.00	0.00
zoo_7_5	7	9	5	2.20	4	0.00	4	0.01	0.00	5	0.00	0.20	4	0.00	0.00	4.2	0.00	0.05
zoo_7_7	7	9	7	2.29	4	0.00	4	0.01	0.00	5	0.00	0.20	4	0.00	0.00	4.4	0.00	0.09
zoo_8_9	8	12	9	2.22	6	0.00	6	0.01	0.00	6	0.00	0.00	6	0.00	0.00	6.5	0.00	0.08
zoo_8_12	8	13	12	2.33	6	0.01	6	0.01	0.00	7	0.00	0.14	7	0.00	0.14	7.0	0.00	0.14
zoo_9_6	7	10	6	2.00	6	0.00	6	0.01	0.00	6	0.00	0.00	6	0.00	0.00	6.0	0.00	0.00
zoo_10_4	7	8	4	2.25	3	0.01	3	0.01	0.00	3	0.00	0.00	3	0.00	0.00	3.6	0.00	0.17
zoo_10_8	8	11	8	2.62	4	0.01	4	0.01	0.00	4	0.00	0.00	4	0.00	0.00	4.7	0.00	0.15
zoo_10_12	10	14	12	2.58	5	0.01	5	0.01	0.00	6	0.00	0.17	6	0.00	0.17	6.1	0.00	0.18
zoo_10_16	10	14	16	2.50	5	0.01	5	0.01	0.00	6	0.00	0.17	6	0.00	0.17	6.2	0.00	0.19
zoo_10_20	10	14	20	2.60	5	0.01	5	0.01	0.00	5	0.00	0.00	5	0.00	0.00	6.4	0.00	0.22
zoo_11_6	10	11	6	2.67	5	0.00	5	0.01	0.00	5	0.00	0.00	5	0.00	0.00	5.0	0.00	0.00
zoo_11_12	9	14	12	2.42	6	0.01	6	0.01	0.00	6	0.00	0.00	7	0.00	0.14	7.9	0.00	0.24
zoo_12_6	8	11	6	2.17	5	0.00	5	0.01	0.00	6	0.00	0.17	5	0.00	0.00	5.0	0.00	0.00
zoo_12_9	11	15	9	2.44	8	0.00	8	0.01	0.00	9	0.00	0.11	8	0.00	0.00	8.1	0.00	0.01
zoo_12_12	11	15	12	2.75	6	0.01	6	0.01	0.00	6	0.00	0.00	6	0.00	0.00	7.3	0.00	0.18
zoo_12_18	10	15	18	2.78	5	0.01	5	0.02	0.00	6	0.00	0.17	6	0.00	0.17	7.2	0.00	0.31

Instance Name	$\lvert D\rvert$	$\lvert I\rvert$	$\lvert F\rvert$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_12_24	12	19	24	2.75	6	0.01	6	0.09	0.00	8	0.00	0.25	7	0.00	0.14	8.8	0.00	0.32
zoo_12_30	12	19	30	2.80	6	0.01	6	0.02	0.00	8	0.00	0.25	8	0.00	0.25	9.0	0.00	0.33
zoo_13_9	10	13	9	2.11	7	0.01	7	0.01	0.00	8	0.00	0.13	7	0.00	0.00	7.7	0.00	0.09
zoo_13_12	9	15	12	2.50	6	0.01	6	0.01	0.00	6	0.00	0.00	6	0.00	0.00	6.8	0.00	0.12
zoo_13_17	12	18	17	2.88	5	0.01	5	0.01	0.00	7	0.00	0.29	6	0.00	0.17	8.1	0.00	0.38
zoo_13_33	13	18	33	2.88	6	0.01	6	0.02	0.00	7	0.00	0.14	7	0.00	0.14	7.6	0.00	0.21
zoo_14_9	10	13	9	3.00	4	0.01	4	0.01	0.00	5	0.00	0.20	4	0.00	0.00	5.0	0.00	0.20
zoo_14_17	14	19	17	2.59	7	0.01	7	0.01	0.00	8	0.00	0.13	9	0.00	0.22	9.2	0.00	0.24
zoo_14_25	13	21	25	2.96	6	0.01	6	0.01	0.00	10	0.00	0.40	8	0.00	0.25	9.0	0.00	0.33
zoo_14_33	14	22	33	2.94	7	0.01	7	0.03	0.00	9	0.00	0.22	9	0.00	0.22	9.8	0.00	0.29
zoo_14_42	14	22	42	3.00	7	0.01	7	0.03	0.00	9	0.00	0.22	9	0.00	0.22	10.6	0.00	0.34
zoo_15_15	13	21	15	2.40	11	0.01	11	0.01	0.00	12	0.00	0.08	12	0.00	0.08	12.0	0.00	0.08
zoo_15_45	15	21	45	3.16	7	0.01	7	0.03	0.00	8	0.00	0.13	8	0.00	0.13	10.2	0.00	0.31
zoo_16_12	11	13	12	2.67	5	0.01	5	0.01	0.00	6	0.00	0.17	5	0.00	0.00	5.8	0.00	0.14
zoo_16_23	14	21	23	2.83	8	0.01	8	0.02	0.00	9	0.00	0.11	9	0.00	0.11	10.7	0.00	0.25
zoo_16_34	16	25	34	2.79	9	0.01	9	0.04	0.00	11	0.00	0.18	11	0.00	0.18	12.4	0.00	0.27
zoo_16_45	15	24	45	3.16	7	0.01	7	0.04	0.00	8	0.00	0.13	8	0.00	0.13	11.5	0.00	0.39
zoo_16_56	16	25	56	3.07	8	0.02	8	0.05	0.00	9	0.00	0.11	9	0.00	0.11	12.5	0.00	0.36

Instance Name	$\|D\|$	$\|I\|$	$\|F\|$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_17_29	16	37	29	2.00	29	0.00	29	0.03	0.00	29	0.00	0.00	29	0.00	0.00	29.0	0.00	0.00
zoo_18_15	14	23	15	2.00	15	0.00	15	0.02	0.00	15	0.00	0.00	15	0.00	0.00	15.0	0.00	0.00
zoo_18_29	14	20	29	2.59	8	0.01	8	0.02	0.00	10	0.00	0.20	9	0.00	0.11	9.6	0.00	0.17
zoo_18_43	16	25	43	2.72	10	0.01	10	0.04	0.00	13	0.00	0.23	13	0.00	0.23	13.4	0.00	0.25
zoo_18_57	17	26	57	2.72	10	0.01	10	0.04	0.00	10	0.00	0.00	10	0.00	0.00	13.4	0.00	0.25
zoo_18_72	18	28	72	2.89	10	0.02	10	0.07	0.00	10	0.00	0.00	10	0.00	0.00	13.5	0.00	0.26
zoo_19_15	13	18	15	2.60	8	0.01	8	0.01	0.00	9	0.00	0.11	9	0.00	0.11	9.8	0.00	0.18
zoo_19_18	16	21	18	2.50	10	0.01	10	0.01	0.00	10	0.00	0.00	10	0.00	0.00	10.8	0.00	0.07
zoo_19_29	16	23	29	2.62	10	0.01	10	0.02	0.00	10	0.00	0.00	10	0.00	0.00	12.0	0.00	0.17
zoo_19_57	18	30	57	3.07	12	0.02	12	0.05	0.00	12	0.00	0.00	12	0.00	0.00	15.7	0.00	0.24
zoo_19_72	18	30	72	3.00	12	0.02	12	0.06	0.00	12	0.00	0.00	12	0.00	0.00	15.2	0.00	0.21
zoo_20_9	10	14	9	2.11	7	0.01	7	0.01	0.00	8	0.00	0.13	7	0.00	0.00	7.6	0.00	0.08
zoo_20_17	13	17	17	2.41	7	0.01	7	0.01	0.00	9	0.00	0.22	8	0.00	0.13	8.5	0.00	0.18
zoo_20_18	15	17	18	2.89	6	0.01	6	0.01	0.00	7	0.00	0.14	8	0.00	0.25	7.8	0.00	0.23
zoo_20_25	13	18	25	2.56	6	0.01	6	0.01	0.00	8	0.00	0.25	8	0.00	0.25	8.7	0.00	0.31
zoo_20_33	14	20	33	2.64	7	0.01	7	0.02	0.00	8	0.00	0.13	8	0.00	0.13	9.4	0.00	0.26
zoo_20_36	19	26	36	2.67	11	0.01	11	0.02	0.00	13	0.00	0.15	12	0.00	0.08	13.2	0.00	0.17
zoo_20_42	14	20	42	2.71	7	0.01	7	0.02	0.00	7	0.00	0.00	7	0.00	0.00	9.0	0.00	0.22

Instance Name	$\|D\|$	$\|I\|$	$\|F\|$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_20_44	18	22	44	2.84	7	0.01	7	0.03	0.00	9	0.00	0.22	9	0.00	0.22	9.0	0.00	0.22
zoo_20_54	19	27	54	2.94	9	0.01	9	0.07	0.00	11	0.00	0.18	11	0.00	0.18	12.7	0.00	0.29
zoo_20_55	19	27	55	2.89	10	0.02	10	0.09	0.00	12	0.00	0.17	12	0.00	0.17	13.0	0.00	0.23
zoo_20_72	19	27	72	2.96	9	0.02	9	0.07	0.00	11	0.00	0.18	11	0.00	0.18	12.9	0.00	0.30
zoo_20_90	20	29	90	3.07	10	0.02	10	0.06	0.00	10	0.00	0.00	10	0.00	0.00	14.2	0.00	0.30
zoo_21_54	17	24	54	3.13	8	0.02	8	0.03	0.00	9	0.00	0.11	9	0.00	0.11	11.4	0.00	0.30
zoo_22_22	22	30	22	2.18	16	0.01	16	0.01	0.00	17	0.00	0.06	16	0.00	0.00	16.7	0.00	0.04
zoo_22_36	19	28	36	2.89	13	0.02	13	0.05	0.00	14	0.00	0.07	14	0.00	0.07	14.7	0.00	0.12
zoo_22_44	22	32	44	2.55	15	0.01	15	0.04	0.00	17	0.00	0.12	16	0.00	0.06	17.1	0.00	0.12
zoo_22_66	19	26	66	2.76	10	0.02	10	0.40	0.00	11	0.00	0.09	10	0.00	0.00	12.5	0.00	0.20
zoo_22_72	20	29	72	3.24	10	0.02	10	0.08	0.00	11	0.00	0.09	11	0.00	0.09	13.6	0.00	0.26
zoo_22_88	22	47	88	2.83	19	0.02	19	0.11	0.00	23	0.00	0.17	22	0.00	0.14	26.2	0.01	0.27
zoo_22_90	20	29	90	3.31	10	0.03	10	0.04	0.00	10	0.00	0.00	10	0.00	0.00	13.7	0.00	0.27
zoo_22_110	22	32	110	2.82	11	0.02	11	0.08	0.00	11	0.00	0.00	11	0.00	0.00	14.8	0.00	0.26
zoo_24_27	18	27	27	2.37	14	0.01	14	0.02	0.00	14	0.00	0.00	14	0.00	0.00	15.3	0.00	0.08
zoo_24_32	20	26	32	2.56	13	0.01	13	0.02	0.00	14	0.00	0.07	14	0.00	0.07	15.2	0.00	0.14
zoo_24_53	23	36	53	2.64	15	0.01	15	0.03	0.00	18	0.00	0.17	18	0.00	0.17	19.4	0.00	0.23
zoo_24_79	24	38	79	2.91	12	0.02	12	0.04	0.00	18	0.00	0.33	18	0.00	0.33	18.2	0.01	0.34

Instance Name	$\lvert D\rvert$	$\lvert I\rvert$	$\lvert F\rvert$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_24_105	24	39	105	3.01	13	0.02	13	0.14	0.00	14	0.00	0.07	14	0.00	0.07	18.2	0.01	0.29
zoo_24_132	24	39	132	3.08	13	0.03	13	0.17	0.00	13	0.00	0.00	13	0.00	0.00	17.8	0.01	0.27
zoo_25_32	18	25	32	2.84	10	0.01	10	0.02	0.00	12	0.00	0.17	11	0.00	0.09	11.9	0.00	0.16
zoo_25_63	22	39	63	3.21	15	0.02	15	0.07	0.00	19	0.00	0.21	17	0.00	0.12	20.5	0.01	0.27
zoo_26_32	19	31	32	2.91	12	0.01	12	0.02	0.00	15	0.00	0.20	13	0.00	0.08	14.1	0.00	0.15
zoo_26_63	24	43	63	2.87	21	0.01	21	0.06	0.00	23	0.00	0.09	22	0.00	0.05	25.8	0.01	0.19
zoo_26_65	22	37	65	3.08	12	0.03	12	0.07	0.00	17	0.00	0.29	17	0.00	0.29	17.8	0.01	0.33
zoo_26_94	24	44	94	3.22	18	0.03	18	0.21	0.00	21	0.00	0.14	21	0.00	0.14	23.6	0.01	0.24
zoo_26_125	26	49	125	3.36	18	0.04	18	0.39	0.00	21	0.00	0.14	20	0.00	0.10	25.6	0.01	0.30
zoo_26_130	26	43	130	3.36	13	0.04	13	0.12	0.00	16	0.00	0.19	16	0.00	0.19	21.0	0.01	0.38
zoo_26_156	26	50	156	3.38	18	0.04	18	0.60	0.00	22	0.00	0.18	22	0.00	0.18	25.1	0.01	0.28
zoo_28_37	28	33	37	3.05	14	0.01	14	0.02	0.00	15	0.00	0.07	15	0.00	0.07	15.3	0.00	0.08
zoo_28_42	22	34	42	4.38	9	0.02	10	0.10	0.10	13	0.00	0.31	13	0.00	0.31	15.8	0.01	0.43
zoo_28_48	21	33	48	3.33	11	0.02	11	0.04	0.00	15	0.00	0.27	13	0.00	0.15	15.6	0.00	0.29
zoo_28_73	28	41	73	2.92	19	0.02	19	0.09	0.00	21	0.00	0.10	21	0.00	0.10	22.7	0.01	0.16
zoo_28_109	27	39	109	3.16	14	0.03	14	0.11	0.00	16	0.00	0.13	16	0.00	0.13	19.8	0.01	0.29
zoo_28_145	27	38	145	3.09	13	0.03	13	0.10	0.00	13	0.00	0.00	13	0.00	0.00	17.9	0.01	0.27
zoo_28_182	28	41	182	3.15	14	0.04	14	0.15	0.00	14	0.00	0.00	14	0.00	0.00	19.5	0.01	0.28

Instance Name	$\|D\|$	$\|I\|$	$\|F\|$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_29_37	21	32	37	3.81	11	0.01	11	0.04	0.00	13	0.00	0.15	12	0.00	0.08	13.3	0.00	0.17
zoo_29_73	26	45	73	3.70	14	0.02	14	0.11	0.00	17	0.00	0.18	17	0.00	0.18	20.7	0.01	0.32
zoo_29_84	26	41	84	4.55	11	0.03	11	0.27	0.00	15	0.00	0.27	15	0.00	0.27	16.6	0.01	0.34
zoo_29_109	28	47	109	3.73	14	0.04	14	0.33	0.00	18	0.00	0.22	18	0.00	0.22	23.1	0.01	0.39
zoo_29_145	26	45	145	3.66	13	0.04	13	0.29	0.00	17	0.00	0.24	17	0.00	0.24	21.8	0.01	0.40
zoo_29_182	28	47	182	3.78	14	0.05	14	0.24	0.00	17	0.00	0.18	17	0.00	0.18	21.9	0.01	0.36
zoo_30_42	19	31	42	2.93	12	0.01	12	0.03	0.00	15	0.00	0.20	14	0.00	0.14	15.1	0.01	0.21
zoo_30_48	23	36	48	3.31	14	0.02	14	0.04	0.00	16	0.00	0.13	15	0.00	0.07	17.2	0.01	0.19
zoo_30_84	27	45	84	4.33	12	0.03	12	0.10	0.00	16	0.00	0.25	15	0.00	0.20	18.9	0.01	0.37
zoo_30_126	28	46	126	4.44	13	0.04	13	0.17	0.00	16	0.00	0.19	16	0.00	0.19	20.0	0.01	0.35
zoo_30_168	29	47	168	4.27	14	0.06	14	0.35	0.00	17	0.00	0.18	16	0.00	0.13	21.5	0.01	0.35
zoo_30_210	30	48	210	4.41	15	0.13	15	0.35	0.00	21	0.00	0.29	21	0.00	0.29	21.8	0.02	0.31
zoo_31_48	26	43	48	3.46	15	0.02	15	0.08	0.00	18	0.00	0.17	16	0.00	0.06	18.6	0.01	0.19
zoo_31_144	30	47	144	3.65	15	0.10	15	0.29	0.00	16	0.00	0.06	18	0.00	0.17	21.4	0.01	0.30
zoo_32_42	24	31	42	2.95	14	0.01	14	0.04	0.00	15	0.00	0.07	15	0.00	0.07	15.8	0.01	0.11
zoo_32_48	26	39	48	3.44	14	0.02	14	0.06	0.00	16	0.00	0.13	16	0.00	0.13	18.9	0.01	0.26
zoo_32_84	28	39	84	3.33	17	0.02	17	0.12	0.00	18	0.00	0.06	18	0.00	0.06	20.3	0.01	0.16
zoo_32_96	27	49	96	3.53	16	0.03	16	0.22	0.00	21	0.00	0.24	21	0.00	0.24	23.2	0.01	0.31

Instance Name	$\lvert D\rvert$	$\lvert I\rvert$	$\lvert F\rvert$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_32_126	30	45	126	3.32	16	0.04	16	0.63	0.00	17	0.00	0.06	17	0.00	0.06	22.5	0.01	0.29
zoo_32_144	32	56	144	3.55	19	0.04	19	1.26	0.00	23	0.00	0.17	23	0.00	0.17	28.5	0.01	0.33
zoo_32_168	30	46	168	3.27	16	0.04	16	0.42	0.00	18	0.00	0.11	18	0.00	0.11	23.0	0.01	0.30
zoo_32_192	32	56	192	3.65	19	0.05	19	1.56	0.00	22	0.00	0.14	22	0.00	0.14	27.6	0.02	0.31
zoo_32_240	32	57	240	3.76	19	0.07	19	1.53	0.00	21	0.00	0.10	21	0.00	0.10	27.8	0.02	0.32
zoo_33_55	28	56	55	2.55	28	0.01	28	0.03	0.00	33	0.00	0.15	29	0.00	0.03	32.7	0.01	0.14
zoo_34_55	26	45	55	5.56	12	0.03	13	0.27	0.08	17	0.00	0.29	16	0.00	0.25	18.0	0.01	0.33
zoo_34_109	34	73	109	2.81	33	0.03	33	0.12	0.00	37	0.00	0.11	36	0.00	0.08	40.3	0.02	0.18
zoo_34_163	33	57	163	3.47	22	0.05	22	0.61	0.00	25	0.00	0.12	25	0.00	0.12	30.6	0.02	0.28
zoo_34_217	33	54	217	4.90	17	0.15	17	0.37	0.00	20	0.00	0.15	19	0.00	0.11	24.9	0.02	0.32
zoo_34_272	34	80	272	3.12	35	0.08	35	1.99	0.00	41	0.00	0.15	41	0.00	0.15	44.6	0.03	0.22
zoo_35_62	27	36	62	3.73	16	0.02	16	0.08	0.00	18	0.00	0.11	18	0.00	0.11	19.1	0.01	0.16
zoo_35_123	32	59	123	4.28	17	0.04	18	0.58	0.06	21	0.00	0.19	22	0.00	0.23	27.1	0.02	0.37
zoo_35_184	35	51	184	4.12	19	0.06	19	0.36	0.00	21	0.00	0.10	20	0.00	0.05	26.7	0.02	0.29
zoo_36_62	32	49	62	2.73	24	0.01	24	0.05	0.00	27	0.00	0.11	27	0.00	0.11	27.9	0.01	0.14
zoo_36_69	26	40	69	3.46	13	0.02	13	0.11	0.00	17	0.00	0.24	17	0.00	0.24	18.9	0.01	0.31
zoo_36_123	32	47	123	5.76	14	0.05	14	0.18	0.00	17	0.00	0.18	15	0.00	0.07	20.0	0.02	0.30
zoo_36_184	34	49	184	6.01	16	0.11	16	0.27	0.00	19	0.00	0.16	19	0.00	0.16	22.7	0.02	0.30

Instance Name	$\lvert D\rvert$	$\lvert I\rvert$	$\lvert F\rvert$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_36_185	35	68	185	3.76	21	0.07	21	4.78	0.00	26	0.00	0.19	28	0.00	0.25	31.5	0.02	0.33
zoo_36_245	36	63	245	3.22	24	0.07	24	0.25	0.00	27	0.00	0.11	27	0.00	0.11	33.1	0.02	0.27
zoo_36_306	36	53	306	6.39	18	0.30	18	0.43	0.00	20	0.01	0.10	20	0.01	0.10	24.8	0.03	0.27
zoo_37_69	25	40	69	3.64	16	0.03	16	0.14	0.00	17	0.00	0.06	17	0.00	0.06	21.7	0.01	0.26
zoo_37_76	33	60	76	3.18	20	0.02	20	0.08	0.00	24	0.00	0.17	20	0.00	0.00	27.3	0.01	0.27
zoo_38_69	32	54	69	2.75	27	0.02	27	0.06	0.00	30	0.00	0.10	27	0.00	0.00	30.5	0.01	0.11
zoo_38_137	34	56	137	4.60	15	0.05	16	0.39	0.06	21	0.00	0.29	20	0.00	0.25	24.5	0.01	0.39
zoo_38_205	36	58	205	4.81	17	0.15	17	0.40	0.00	20	0.00	0.15	20	0.00	0.15	26.3	0.03	0.35
zoo_38_273	38	60	273	4.82	19	0.18	19	0.54	0.00	22	0.00	0.14	22	0.00	0.14	27.9	0.02	0.32
zoo_38_342	38	60	342	4.84	19	0.21	19	0.61	0.00	23	0.00	0.17	23	0.00	0.17	28.2	0.03	0.33
zoo_39_152	35	71	152	3.52	25	0.09	25	0.46	0.00	32	0.00	0.22	30	0.00	0.17	34.4	0.02	0.27
zoo_39_228	37	75	228	3.59	23	0.08	23	1.33	0.00	31	0.01	0.26	29	0.00	0.21	35.5	0.03	0.35
zoo_40_76	30	43	76	2.88	21	0.02	21	0.08	0.00	22	0.00	0.05	21	0.00	0.00	23.9	0.01	0.12
zoo_40_152	38	56	152	3.22	23	0.04	23	0.17	0.00	26	0.00	0.12	26	0.00	0.12	29.9	0.01	0.23
zoo_40_228	40	60	228	3.37	20	0.06	20	0.28	0.00	25	0.01	0.20	25	0.00	0.20	30.8	0.02	0.35
zoo_40_304	40	60	304	3.55	20	0.08	20	0.18	0.00	21	0.00	0.05	20	0.00	0.00	29.8	0.02	0.33
zoo_40_380	40	61	380	3.63	20	0.10	20	0.45	0.00	20	0.01	0.00	20	0.00	0.00	30.3	0.03	0.34
zoo_42_84	35	58	84	4.14	22	0.04	22	0.20	0.00	28	0.00	0.21	27	0.00	0.19	28.3	0.01	0.22

Instance Name	$\lvert D\rvert$	$\lvert I\rvert$	$\lvert F\rvert$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_42_168	36	60	168	4.46	20	0.06	20	0.77	0.00	23	0.00	0.13	23	0.00	0.13	29.1	0.02	0.31
zoo_42_185	40	56	185	3.82	22	0.10	22	0.51	0.00	24	0.00	0.08	24	0.00	0.08	29.2	0.02	0.25
zoo_42_252	41	74	252	4.47	23	0.17	23	3.90	0.00	32	0.01	0.28	30	0.00	0.23	37.8	0.03	0.39
zoo_42_336	42	76	336	4.60	24	0.12	24	3.78	0.00	30	0.01	0.20	30	0.00	0.20	38.2	0.04	0.37
zoo_42_420	42	76	420	4.64	24	0.15	24	4.10	0.00	30	0.01	0.20	30	0.01	0.20	38.6	0.05	0.38
zoo_43_84	37	60	84	3.57	22	0.03	22	0.16	0.00	26	0.00	0.15	23	0.00	0.04	28.3	0.01	0.22
zoo_43_93	40	65	93	3.99	24	0.03	25	0.11	0.04	29	0.00	0.17	28	0.00	0.14	30.3	0.02	0.21
zoo_43_168	38	65	168	3.95	20	0.07	20	2.97	0.00	25	0.00	0.20	22	0.00	0.09	31.5	0.02	0.37
zoo_43_252	42	76	252	3.91	26	0.09	26	1.44	0.00	34	0.00	0.24	34	0.00	0.24	37.7	0.03	0.31
zoo_43_336	39	75	336	4.01	23	0.11	23	3.14	0.00	31	0.01	0.26	31	0.00	0.26	39.3	0.04	0.41
zoo_43_420	42	78	420	4.03	23	0.24	23	1.70	0.00	31	0.01	0.26	31	0.00	0.26	39.9	0.04	0.42
zoo_44_93	34	62	93	4.11	20	0.04	21	0.26	0.05	24	0.00	0.17	21	0.00	0.05	28.5	0.02	0.30
zoo_44_102	34	58	102	5.95	16	0.04	17	0.60	0.06	21	0.00	0.24	22	0.00	0.27	22.9	0.02	0.30
zoo_44_185	40	69	185	4.39	21	0.13	22	0.98	0.05	27	0.00	0.22	26	0.00	0.19	32.3	0.02	0.35
zoo_44_277	42	76	277	4.53	22	0.10	22	6.30	0.00	26	0.01	0.15	28	0.00	0.21	35.8	0.03	0.39
zoo_44_369	43	79	369	4.88	24	0.14	24	6.17	0.00	32	0.01	0.25	32	0.00	0.25	38.4	0.05	0.38
zoo_44_462	44	81	462	4.95	25	0.32	25	20.32	0.00	32	0.01	0.22	32	0.01	0.22	39.0	0.05	0.36
zoo_45_93	40	57	93	3.08	27	0.03	27	0.10	0.00	28	0.00	0.04	27	0.00	0.00	30.1	0.01	0.10

Instance Name	$\lvert D\rvert$	$\lvert I\rvert$	$\lvert F\rvert$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_45_102	32	68	102	2.81	42	0.03	42	0.10	0.00	49	0.00	0.14	45	0.00	0.07	46.6	0.02	0.10
zoo_45_185	43	63	185	3.38	24	0.06	24	0.55	0.00	28	0.00	0.14	27	0.00	0.11	31.0	0.02	0.23
zoo_45_277	44	69	277	3.57	24	0.08	24	6.15	0.00	31	0.01	0.23	31	0.00	0.23	34.9	0.03	0.31
zoo_45_304	45	72	304	3.23	24	0.09	24	1.05	0.00	28	0.01	0.14	28	0.00	0.14	34.9	0.03	0.31
zoo_45_370	44	69	370	3.78	22	0.11	22	1.22	0.00	27	0.01	0.19	27	0.00	0.19	32.2	0.03	0.32
zoo_45_462	44	69	462	3.95	22	0.14	22	0.95	0.00	23	0.01	0.04	23	0.00	0.04	33.3	0.04	0.34
zoo_46_102	41	54	102	3.64	23	0.03	23	0.13	0.00	26	0.00	0.12	25	0.00	0.08	27.2	0.01	0.15
zoo_46_203	42	65	203	6.12	22	0.17	22	16.79	0.00	25	0.01	0.12	25	0.00	0.12	30.3	0.03	0.27
zoo_46_205	44	69	205	3.14	25	0.06	25	1.58	0.00	31	0.00	0.19	31	0.00	0.19	33.9	0.02	0.26
zoo_46_304	42	64	304	5.95	20	0.12	20	1.68	0.00	23	0.01	0.13	24	0.00	0.17	28.8	0.03	0.31
zoo_46_405	45	69	405	6.14	22	0.18	22	1.61	0.00	28	0.01	0.21	26	0.01	0.15	31.9	0.05	0.31
zoo_46_406	46	69	406	4.26	23	0.14	23	1.09	0.00	26	0.01	0.12	26	0.00	0.12	34.4	0.04	0.33
zoo_46_506	46	72	506	6.22	24	0.37	24	2.57	0.00	28	0.01	0.14	28	0.01	0.14	35.3	0.06	0.32
zoo_47_111	42	79	111	3.48	29	0.04	29	0.13	0.00	37	0.00	0.22	35	0.00	0.17	38.6	0.02	0.25
zoo_47_331	46	72	331	3.28	24	0.09	24	1.89	0.00	29	0.00	0.17	27	0.00	0.11	33.9	0.03	0.29
zoo_48_111	46	72	111	3.07	33	0.03	33	0.14	0.00	40	0.00	0.18	34	0.00	0.03	38.4	0.02	0.14
zoo_48_120	37	57	120	4.45	18	0.04	18	0.56	0.00	24	0.00	0.25	25	0.00	0.28	27.3	0.02	0.34
zoo_48_221	42	84	221	3.73	27	0.08	27	0.95	0.00	37	0.00	0.27	35	0.00	0.23	43.4	0.04	0.38

Instance Name	$\|D\|$	$\|I\|$	$\|F\|$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_48_331	45	85	331	3.82	26	0.11	26	3.40	0.00	36	0.00	0.28	36	0.00	0.28	43.1	0.04	0.40
zoo_48_441	45	87	441	3.89	24	0.17	24	13.15	0.00	31	0.01	0.23	31	0.00	0.23	42.9	0.05	0.44
zoo_48_442	48	70	442	4.00	24	0.13	24	0.81	0.00	27	0.01	0.11	27	0.00	0.11	34.7	0.04	0.31
zoo_48_552	48	93	552	3.95	28	0.43	28	63.19	0.00	38	0.01	0.26	38	0.01	0.26	47.4	0.06	0.41
zoo_50_120	41	57	120	3.65	21	0.04	21	0.22	0.00	25	0.00	0.16	24	0.00	0.13	28.3	0.01	0.26
zoo_50_240	49	74	240	3.77	28	0.07	28	0.71	0.00	35	0.00	0.20	33	0.00	0.15	37.8	0.03	0.26
zoo_50_360	46	69	360	5.32	22	0.15	22	8.88	0.00	26	0.01	0.15	26	0.00	0.15	33.0	0.04	0.33
zoo_50_361	50	77	361	3.95	28	0.11	28	1.46	0.00	32	0.00	0.13	32	0.00	0.13	39.5	0.04	0.29
zoo_50_480	49	79	480	5.43	25	0.33	25	27.10	0.00	31	0.01	0.19	31	0.01	0.19	38.5	0.06	0.35
zoo_50_481	50	78	481	4.11	25	0.25	25	1.15	0.00	31	0.01	0.19	31	0.00	0.19	39.8	0.05	0.37
zoo_50_600	50	78	600	4.22	25	0.32	25	2.42	0.00	27	0.01	0.07	27	0.01	0.07	37.8	0.05	0.34
zoo_52_130	44	74	130	5.53	21	0.07	21	0.71	0.00	27	0.00	0.22	26	0.00	0.19	32.0	0.02	0.34
zoo_52_260	51	79	260	3.47	35	0.08	35	0.93	0.00	39	0.00	0.10	39	0.00	0.10	41.0	0.03	0.15
zoo_52_390	48	83	390	5.67	23	0.18	23	9.72	0.00	32	0.01	0.28	32	0.01	0.28	38.3	0.05	0.40
zoo_52_394	52	81	394	3.70	27	0.13	27	3.44	0.00	34	0.00	0.21	34	0.00	0.21	41.7	0.04	0.35
zoo_52_520	51	86	520	5.34	26	0.37	26	33.90	0.00	31	0.01	0.16	31	0.01	0.16	41.7	0.07	0.38
zoo_52_523	52	81	523	3.87	26	0.16	26	1.50	0.00	31	0.01	0.16	31	0.00	0.16	40.9	0.05	0.36
zoo_52_650	52	91	650	5.52	29	0.49	29	31.93	0.00	39	0.01	0.26	38	0.01	0.24	45.0	0.08	0.36

Instance Name	$\|D\|$	$\|I\|$	$\|F\|$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_54_141	46	71	141	3.70	31	0.05	31	0.23	0.00	33	0.00	0.06	33	0.00	0.06	37.4	0.02	0.17
zoo_54_152	45	80	152	5.54	19	0.07	21	1.97	0.10	29	0.00	0.34	29	0.00	0.34	32.7	0.03	0.42
zoo_54_281	53	96	281	3.46	39	0.09	39	0.86	0.00	45	0.00	0.13	44	0.00	0.11	52.2	0.04	0.25
zoo_54_421	54	104	421	3.61	39	0.15	39	2.13	0.00	48	0.00	0.19	47	0.00	0.17	57.8	0.06	0.33
zoo_54_423	53	82	423	4.17	28	0.23	28	17.72	0.00	34	0.00	0.18	34	0.00	0.18	41.3	0.05	0.32
zoo_54_561	54	104	561	3.74	37	0.20	37	8.42	0.00	41	0.01	0.10	41	0.01	0.10	54.9	0.07	0.33
zoo_54_564	54	84	564	4.39	27	0.32	27	0.91	0.00	30	0.01	0.10	30	0.01	0.10	41.9	0.06	0.36
zoo_54_702	54	104	702	3.94	37	0.27	37	36.15	0.00	41	0.01	0.10	41	0.01	0.10	55.8	0.08	0.34
zoo_55_152	36	51	152	3.93	17	0.08	17	0.26	0.00	21	0.00	0.19	21	0.00	0.19	24.8	0.02	0.31
zoo_55_281	53	82	281	3.92	31	0.10	31	1.10	0.00	34	0.00	0.09	37	0.00	0.16	40.9	0.04	0.24
zoo_55_303	47	86	303	5.50	26	0.12	27	5.00	0.04	34	0.00	0.24	34	0.00	0.24	41.3	0.05	0.37
zoo_55_421	54	86	421	4.19	27	0.16	27	1.68	0.00	31	0.00	0.13	31	0.00	0.13	41.6	0.05	0.35
zoo_55_562	53	84	562	4.47	26	0.21	26	2.93	0.00	32	0.01	0.19	32	0.01	0.19	42.5	0.06	0.39
zoo_55_702	54	86	702	4.44	27	0.28	27	2.84	0.00	29	0.01	0.07	29	0.01	0.07	41.6	0.07	0.35
zoo_56_152	45	72	152	4.97	23	0.06	23	0.59	0.00	29	0.00	0.21	28	0.00	0.18	33.1	0.03	0.31
zoo_56_303	50	73	303	4.19	26	0.10	26	0.53	0.00	31	0.00	0.16	31	0.00	0.16	37.8	0.03	0.31
zoo_56_454	53	94	454	5.58	27	0.34	27	42.60	0.00	38	0.01	0.29	38	0.01	0.29	45.3	0.07	0.40
zoo_56_605	56	99	605	5.84	29	0.36	29	16.57	0.00	39	0.01	0.26	39	0.01	0.26	48.7	0.09	0.40

Instance Name	$\lvert D\rvert$	$\lvert I\rvert$	$\lvert F\rvert$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
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zoo_56_617	56	85	617	4.26	28	0.25	28	2.29	0.00	34	0.01	0.18	34	0.01	0.18	43.1	0.06	0.35
zoo_56_756	56	99	756	5.74	29	0.37	29	24.46	0.00	40	0.01	0.28	40	0.01	0.28	48.7	0.10	0.40
zoo_57_325	54	109	325	3.45	39	0.15	39	1.71	0.00	51	0.00	0.24	50	0.00	0.22	59.9	0.05	0.35
zoo_58_163	56	109	163	3.17	53	0.06	53	0.19	0.00	55	0.00	0.04	55	0.00	0.04	62.6	0.04	0.15
zoo_58_325	54	88	325	3.50	31	0.11	31	1.60	0.00	39	0.00	0.21	38	0.00	0.18	44.5	0.04	0.30
zoo_58_487	58	119	487	3.61	39	0.29	39	3.57	0.00	53	0.00	0.26	53	0.00	0.26	64.5	0.08	0.40
zoo_58_649	58	117	649	3.67	36	0.46	36	44.84	0.00	51	0.01	0.29	50	0.01	0.28	65.6	0.09	0.45
zoo_58_650	58	95	650	3.84	30	0.24	30	18.13	0.00	35	0.01	0.14	35	0.01	0.14	45.9	0.06	0.35
zoo_58_812	58	120	812	3.68	36	0.59	36	23.54	0.00	49	0.01	0.27	49	0.01	0.27	64.8	0.10	0.44
zoo_59_174	47	79	174	3.41	33	0.05	33	0.42	0.00	41	0.00	0.20	40	0.00	0.18	45.0	0.03	0.27
zoo_59_348	54	80	348	3.85	29	0.17	29	1.41	0.00	35	0.00	0.17	34	0.00	0.15	42.0	0.04	0.31
zoo_60_174	38	59	174	3.60	23	0.05	23	0.26	0.00	24	0.00	0.04	25	0.00	0.08	30.9	0.02	0.26
zoo_60_348	55	92	348	3.54	32	0.12	32	0.78	0.00	40	0.00	0.20	38	0.00	0.16	48.0	0.04	0.33
zoo_60_350	58	83	350	3.63	37	0.11	37	0.55	0.00	42	0.00	0.12	42	0.00	0.12	44.5	0.04	0.17
zoo_60_351	59	87	351	3.40	39	0.10	39	0.57	0.00	43	0.00	0.09	43	0.00	0.09	49.5	0.04	0.21
zoo_60_522	58	92	522	4.02	34	0.21	34	4.49	0.00	39	0.01	0.13	39	0.01	0.13	50.5	0.06	0.33
zoo_60_524	59	87	524	3.86	34	0.17	34	8.31	0.00	40	0.01	0.15	40	0.01	0.15	46.5	0.05	0.27
zoo_60_527	59	87	527	3.69	30	0.16	30	0.89	0.00	40	0.00	0.25	39	0.00	0.23	47.2	0.05	0.36

Instance Name	$\|D\|$	$\|I\|$	$\|F\|$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_60_696	60	97	696	4.16	35	0.28	35	5.17	0.00	39	0.01	0.10	40	0.01	0.13	53.5	0.08	0.35
zoo_60_715	59	87	715	3.87	29	0.26	29	1.69	0.00	34	0.01	0.15	34	0.01	0.15	45.2	0.07	0.36
zoo_60_720	60	89	720	3.71	30	0.25	30	1.12	0.00	35	0.01	0.14	36	0.01	0.17	46.8	0.06	0.36
zoo_60_870	60	97	870	4.24	35	0.36	35	3.57	0.00	35	0.01	0.00	35	0.01	0.00	53.5	0.09	0.35
zoo_61_174	42	85	174	3.18	37	0.06	37	0.40	0.00	44	0.00	0.16	42	0.00	0.12	48.0	0.03	0.23
zoo_61_372	54	92	372	5.65	24	0.17	26	44.57	0.08	33	0.01	0.27	32	0.01	0.25	40.6	0.06	0.41
zoo_62_186	51	81	186	5.66	23	0.08	23	1.55	0.00	29	0.00	0.21	28	0.00	0.18	35.0	0.04	0.34
zoo_62_558	61	100	558	3.64	32	0.37	32	8.57	0.00	38	0.01	0.16	38	0.01	0.16	47.9	0.06	0.33
zoo_62_744	62	102	744	3.74	31	0.52	31	2.12	0.00	35	0.01	0.11	35	0.01	0.11	47.5	0.07	0.35
zoo_62_745	60	100	745	5.74	29	0.43	29	5.93	0.00	37	0.01	0.22	37	0.01	0.22	46.9	0.09	0.38
zoo_62_930	62	102	930	3.82	31	0.51	31	3.08	0.00	32	0.01	0.03	32	0.01	0.03	47.1	0.09	0.34
zoo_63_595	61	92	595	5.10	30	0.29	30	41.70	0.00	34	0.01	0.12	35	0.01	0.14	46.5	0.07	0.35
zoo_64_199	58	88	199	5.06	34	0.09	34	0.46	0.00	41	0.00	0.17	39	0.00	0.13	43.1	0.04	0.21
zoo_64_348	54	114	348	3.55	46	0.18	46	2.45	0.00	55	0.00	0.16	52	0.00	0.12	64.2	0.06	0.28
zoo_64_397	61	91	397	5.03	31	0.18	32	2.74	0.03	39	0.01	0.21	39	0.01	0.21	46.6	0.05	0.33
zoo_64_522	57	132	522	3.71	54	0.22	54	5.83	0.00	66	0.01	0.18	62	0.01	0.13	72.5	0.08	0.26
zoo_64_595	63	111	595	4.48	38	0.28	38	10.40	0.00	46	0.01	0.17	46	0.01	0.17	61.4	0.08	0.38
zoo_64_696	58	136	696	3.88	55	0.31	55	12.72	0.00	68	0.01	0.19	65	0.01	0.15	78.5	0.11	0.30

Instance Name	$\lvert D\rvert$	$\lvert I\rvert$	$\lvert F\rvert$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_64_793	63	96	793	5.35	31	0.64	31	3.73	0.00	36	0.01	0.14	36	0.01	0.14	48.4	0.09	0.36
zoo_64_870	60	141	870	3.95	55	0.43	55	18.94	0.00	72	0.01	0.24	71	0.01	0.23	80.1	0.14	0.31
zoo_64_992	64	99	992	5.42	32	0.64	32	4.88	0.00	35	0.01	0.09	35	0.01	0.09	50.7	0.11	0.37
zoo_65_212	56	97	212	3.58	41	0.09	41	0.57	0.00	49	0.00	0.16	45	0.00	0.09	49.1	0.03	0.16
zoo_65_634	65	118	634	3.93	42	0.27	42	4.53	0.00	53	0.01	0.21	52	0.01	0.19	60.9	0.08	0.31
zoo_66_212	58	91	212	3.63	37	0.09	37	0.35	0.00	43	0.00	0.14	43	0.00	0.14	48.6	0.04	0.24
zoo_66_423	64	111	423	3.84	43	0.17	43	2.52	0.00	51	0.00	0.16	51	0.00	0.16	60.0	0.07	0.28
zoo_66_634	65	119	634	3.94	38	0.30	38	24.13	0.00	46	0.01	0.17	44	0.01	0.14	61.0	0.08	0.38
zoo_66_635	62	105	635	5.61	29	0.51	29	11.30	0.00	39	0.01	0.26	39	0.01	0.26	48.5	0.08	0.40
zoo_66_845	66	120	845	4.05	39	0.38	39	9.62	0.00	49	0.01	0.20	49	0.01	0.20	63.6	0.11	0.39
zoo_66_846	66	118	846	4.08	38	0.74	38	16.24	0.00	49	0.01	0.22	49	0.01	0.22	62.0	0.11	0.39
zoo_66_847	65	109	847	5.79	33	0.47	33	7.26	0.00	39	0.01	0.15	38	0.01	0.13	52.2	0.11	0.37
zoo_66_1056	66	120	1056	4.10	39	0.78	39	43.04	0.00	45	0.01	0.13	45	0.01	0.13	63.2	0.13	0.38
zoo_67_225	59	110	225	4.01	37	0.10	37	1.57	0.00	49	0.00	0.24	44	0.00	0.16	54.3	0.04	0.32
zoo_68_225	51	97	225	4.04	32	0.11	32	1.01	0.00	43	0.00	0.26	39	0.00	0.18	45.6	0.04	0.30
zoo_68_449	62	123	449	4.19	36	0.32	36	5.33	0.00	52	0.00	0.31	49	0.01	0.27	61.8	0.07	0.42
zoo_68_673	63	126	673	4.13	36	0.52	36	72.28	0.00	52	0.01	0.31	52	0.01	0.31	64.7	0.10	0.44
zoo_68_897	67	131	897	4.25	36	0.61	37	269.01	0.03	50	0.01	0.28	49	0.01	0.27	66.9	0.13	0.46

Instance Name	$\lvert D\rvert$	$\lvert I\rvert$	$\lvert F\rvert$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_68_1122	68	133	1122	4.31	38	1.21	38	3427.86	0.00	48	0.01	0.21	48	0.01	0.21	69.0	0.15	0.45
zoo_69_238	55	92	238	6.18	22	0.19	25	50.02	0.12	34	0.00	0.35	31	0.00	0.29	37.9	0.04	0.42
zoo_70_238	67	102	238	3.32	46	0.08	46	0.52	0.00	51	0.00	0.10	51	0.00	0.10	55.4	0.04	0.17
zoo_70_252	61	101	252	5.46	30	0.14	31	5.04	0.03	40	0.00	0.25	40	0.00	0.25	46.4	0.05	0.35
zoo_70_476	67	106	476	5.94	33	0.25	35	13.93	0.06	43	0.01	0.23	40	0.01	0.18	51.3	0.08	0.36
zoo_70_714	66	109	714	5.99	31	0.76	31	10.29	0.00	38	0.01	0.18	37	0.01	0.16	51.5	0.10	0.40
zoo_70_953	70	110	953	3.78	35	0.43	35	3.80	0.00	41	0.01	0.15	41	0.01	0.15	57.0	0.10	0.39
zoo_70_1190	70	114	1190	6.15	35	1.42	35	6.91	0.00	44	0.02	0.20	44	0.02	0.20	55.1	0.15	0.36
zoo_71_238	63	86	238	5.20	40	0.09	41	0.99	0.02	44	0.00	0.09	44	0.00	0.09	46.5	0.04	0.14
zoo_71_477	67	95	477	5.69	36	0.22	36	1.69	0.00	41	0.01	0.12	44	0.01	0.18	51.7	0.07	0.30
zoo_71_719	70	103	719	6.12	37	0.36	37	2.51	0.00	41	0.01	0.10	41	0.01	0.10	55.4	0.10	0.33
zoo_71_953	70	103	953	6.15	35	0.47	36	3.24	0.03	40	0.02	0.13	41	0.02	0.15	56.8	0.13	0.38
zoo_71_1190	70	104	1190	6.31	35	0.71	35	6.51	0.00	36	0.02	0.03	36	0.02	0.03	55.8	0.15	0.37
zoo_72_252	70	105	252	3.35	44	0.09	44	0.75	0.00	47	0.00	0.06	46	0.00	0.04	52.9	0.04	0.17
zoo_72_255	70	115	255	4.36	49	0.20	49	1.33	0.00	58	0.00	0.16	55	0.00	0.11	62.9	0.05	0.22
zoo_72_504	68	113	504	5.74	34	0.69	35	97.33	0.03	40	0.01	0.15	43	0.01	0.21	54.6	0.08	0.38
zoo_72_506	71	113	506	4.39	37	0.22	37	3.45	0.00	47	0.01	0.21	49	0.01	0.24	56.7	0.07	0.35
zoo_72_756	69	113	756	5.56	33	0.46	33	5.04	0.00	41	0.01	0.20	42	0.01	0.21	52.6	0.10	0.37

Instance Name	$\|D\|$	$\|I\|$	$\|F\|$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_72_765	70	114	765	4.70	36	0.52	36	60.32	0.00	44	0.01	0.18	44	0.01	0.18	57.6	0.10	0.38
zoo_72_1008	72	119	1008	5.73	36	0.98	37	7.01	0.03	40	0.01	0.10	41	0.02	0.12	58.5	0.14	0.38
zoo_72_1010	71	116	1010	4.68	37	0.54	37	8.44	0.00	44	0.01	0.16	44	0.01	0.16	58.2	0.12	0.36
zoo_72_1260	72	119	1260	5.78	36	1.14	36	11.16	0.00	40	0.02	0.10	40	0.02	0.10	56.9	0.16	0.37
zoo_73_267	58	109	267	3.87	38	0.12	38	0.97	0.00	47	0.00	0.19	43	0.00	0.12	54.9	0.04	0.31
zoo_73_533	68	113	533	4.52	38	0.33	38	26.48	0.00	46	0.01	0.17	45	0.01	0.16	57.0	0.08	0.33
zoo_73_1065	72	118	1065	4.32	36	0.52	36	10.64	0.00	42	0.01	0.14	42	0.01	0.14	59.9	0.12	0.40
zoo_74_267	69	107	267	2.98	57	0.09	57	0.42	0.00	58	0.00	0.02	58	0.00	0.02	61.5	0.04	0.07
zoo_74_533	74	160	533	3.21	74	0.26	74	2.29	0.00	90	0.00	0.18	86	0.00	0.14	95.8	0.12	0.23
zoo_74_799	73	160	799	3.34	66	0.38	66	7.21	0.00	85	0.01	0.22	83	0.01	0.20	92.5	0.15	0.29
zoo_74_800	74	121	800	4.09	38	0.52	38	6.85	0.00	46	0.01	0.17	46	0.01	0.17	60.3	0.10	0.37
zoo_74_1065	74	167	1065	3.45	69	0.74	69	14.73	0.00	86	0.01	0.20	86	0.01	0.20	96.1	0.19	0.28
zoo_74_1075	74	116	1075	3.59	37	0.47	37	4.20	0.00	44	0.01	0.16	44	0.01	0.16	55.8	0.11	0.34
zoo_74_1332	74	116	1332	3.67	37	0.55	37	6.34	0.00	38	0.01	0.03	38	0.01	0.03	56.7	0.14	0.35
zoo_75_282	65	110	282	4.62	35	0.12	37	2.63	0.05	44	0.00	0.20	46	0.00	0.24	51.9	0.06	0.33
zoo_76_282	73	107	282	3.57	54	0.10	54	0.71	0.00	57	0.00	0.05	58	0.00	0.07	60.7	0.05	0.11
zoo_76_563	74	125	563	5.02	39	0.34	40	103.63	0.03	52	0.01	0.25	52	0.01	0.25	62.0	0.10	0.37
zoo_76_844	76	128	844	5.05	40	0.43	41	6.13	0.02	52	0.01	0.23	50	0.01	0.20	64.1	0.13	0.38

Instance Name	$\lvert D\rvert$	$\lvert I\rvert$	$\lvert F\rvert$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_76_846	76	115	846	4.09	40	0.40	40	21.84	0.00	52	0.01	0.23	52	0.01	0.23	62.9	0.10	0.36
zoo_76_1125	76	128	1125	5.13	39	1.30	39	55.85	0.00	47	0.01	0.17	47	0.02	0.17	61.9	0.15	0.37
zoo_76_1126	76	115	1126	4.19	38	0.58	38	5.20	0.00	43	0.01	0.12	43	0.01	0.12	62.4	0.13	0.39
zoo_76_1406	76	129	1406	5.30	39	0.83	39	38.35	0.00	48	0.02	0.19	48	0.02	0.19	62.5	0.18	0.38
zoo_78_199	42	107	199	3.02	50	0.07	50	0.38	0.00	61	0.00	0.18	56	0.00	0.11	64.3	0.04	0.22
zoo_78_297	58	97	297	6.09	31	0.25	32	5.78	0.03	41	0.01	0.24	38	0.01	0.18	46.8	0.06	0.34
zoo_78_397	56	139	397	3.16	63	0.20	63	1.85	0.00	77	0.00	0.18	75	0.00	0.16	83.5	0.07	0.25
zoo_78_593	73	129	593	6.84	40	0.39	40	85.97	0.00	52	0.01	0.23	51	0.01	0.22	64.6	0.14	0.38
zoo_78_595	63	152	595	3.36	63	0.30	63	4.76	0.00	77	0.01	0.18	73	0.01	0.14	89.8	0.11	0.30
zoo_78_793	64	158	793	3.53	61	0.39	61	9.37	0.00	76	0.01	0.20	74	0.01	0.18	90.5	0.14	0.33
zoo_78_889	77	137	889	7.05	41	0.90	43	106.48	0.05	60	0.02	0.32	58	0.02	0.29	69.6	0.17	0.41
zoo_78_890	77	126	890	3.86	41	0.42	41	29.36	0.00	51	0.01	0.20	50	0.01	0.18	66.1	0.11	0.38
zoo_78_891	78	128	891	3.85	42	0.48	43	30.75	0.02	52	0.01	0.19	52	0.01	0.19	67.3	0.12	0.38
zoo_78_992	64	159	992	3.69	61	0.54	61	22.46	0.00	76	0.01	0.20	75	0.01	0.19	91.1	0.17	0.33
zoo_78_1185	77	140	1185	7.17	44	1.00	44	133.49	0.00	58	0.02	0.24	57	0.03	0.23	72.8	0.22	0.40
zoo_78_1482	78	142	1482	7.29	45	2.93	45	167.46	0.00	60	0.03	0.25	59	0.03	0.24	74.4	0.26	0.40
zoo_79_328	64	102	328	3.42	43	0.12	43	1.41	0.00	52	0.00	0.17	50	0.00	0.14	55.9	0.04	0.23
zoo_79_624	64	130	624	3.99	44	0.31	44	6.14	0.00	57	0.01	0.23	52	0.01	0.15	67.7	0.09	0.35

Instance Name	$\lvert D\rvert$	$\lvert I\rvert$	$\lvert F\rvert$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_80_312	54	110	312	4.14	37	0.12	38	2.10	0.03	47	0.00	0.21	43	0.00	0.14	55.1	0.05	0.33
zoo_80_936	72	144	936	4.19	45	0.88	45	142.84	0.00	56	0.01	0.20	56	0.01	0.20	72.7	0.14	0.38
zoo_80_1248	80	162	1248	4.34	52	1.58	52	127.71	0.00	63	0.01	0.17	63	0.01	0.17	83.9	0.21	0.38
zoo_80_1560	80	163	1560	4.53	52	1.07	52	143.51	0.00	63	0.02	0.17	63	0.02	0.17	82.7	0.25	0.37
zoo_82_656	79	137	656	3.59	56	0.31	56	5.90	0.00	66	0.01	0.15	66	0.01	0.15	75.4	0.10	0.26
zoo_82_984	82	144	984	3.72	54	0.50	54	15.28	0.00	65	0.01	0.17	65	0.01	0.17	79.1	0.15	0.32
zoo_82_1315	82	152	1315	3.83	55	0.72	55	105.34	0.00	67	0.01	0.18	66	0.01	0.17	84.2	0.22	0.35
zoo_82_1640	82	158	1640	3.94	61	0.93	61	68.83	0.00	66	0.02	0.08	66	0.02	0.08	88.8	0.25	0.31
zoo_84_345	75	135	345	3.95	54	0.20	54	1.22	0.00	66	0.00	0.18	64	0.00	0.16	71.4	0.09	0.24
zoo_84_689	81	157	689	4.01	57	0.36	57	6.17	0.00	70	0.01	0.19	69	0.01	0.17	84.7	0.13	0.33
zoo_84_1033	84	167	1033	4.08	54	1.15	54	47.88	0.00	78	0.01	0.31	77	0.01	0.30	87.7	0.18	0.38
zoo_84_1377	84	169	1377	4.19	51	2.07	51	175.76	0.00	71	0.01	0.28	70	0.01	0.27	89.5	0.23	0.43
zoo_84_1722	84	169	1722	4.25	50	2.94	50	3602.84	0.00	67	0.02	0.25	66	0.02	0.24	89.3	0.28	0.44
zoo_86_362	75	118	362	5.98	41	0.18	42	2.08	0.02	45	0.01	0.09	46	0.01	0.11	55.7	0.08	0.26
zoo_86_723	75	117	723	6.60	34	0.47	35	23.58	0.03	41	0.01	0.17	41	0.01	0.17	54.2	0.12	0.37
zoo_86_724	84	148	724	4.61	47	0.66	47	22.75	0.00	62	0.01	0.24	62	0.01	0.24	74.3	0.13	0.37
zoo_86_1084	80	126	1084	6.62	39	1.03	39	11.47	0.00	49	0.02	0.20	49	0.02	0.20	59.1	0.16	0.34
zoo_86_1445	84	127	1445	6.71	41	1.37	41	13.09	0.00	48	0.03	0.15	48	0.03	0.15	59.6	0.21	0.31

Instance Name	$\|D\|$	$\|I\|$	$\|F\|$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_86_1446	86	130	1446	3.92	43	0.72	43	35.17	0.00	50	0.01	0.14	50	0.01	0.14	70.9	0.18	0.39
zoo_86_1806	86	134	1806	6.83	43	2.36	43	15.22	0.00	47	0.04	0.09	47	0.04	0.09	65.8	0.27	0.35
zoo_88_379	66	101	379	3.42	43	0.13	43	1.49	0.00	50	0.00	0.14	48	0.00	0.10	58.2	0.05	0.26
zoo_88_757	88	146	757	3.56	56	0.35	56	3.93	0.00	67	0.01	0.16	67	0.01	0.16	77.3	0.12	0.28
zoo_88_758	88	129	758	3.71	53	0.51	53	6.51	0.00	61	0.01	0.13	61	0.01	0.13	71.6	0.11	0.26
zoo_88_1135	88	147	1135	3.76	49	0.60	49	38.39	0.00	63	0.01	0.22	63	0.01	0.22	76.0	0.16	0.36
zoo_88_1514	88	147	1514	3.88	45	0.80	45	53.28	0.00	52	0.01	0.13	52	0.02	0.13	73.7	0.20	0.39
zoo_88_1518	88	131	1518	3.94	44	0.75	44	11.37	0.00	48	0.01	0.08	48	0.02	0.08	70.0	0.18	0.37
zoo_88_1892	88	147	1892	3.94	45	1.10	45	48.77	0.00	49	0.02	0.08	49	0.02	0.08	70.9	0.25	0.37
zoo_89_396	67	124	396	5.52	35	0.31	37	54.37	0.05	48	0.01	0.27	50	0.01	0.30	58.7	0.08	0.40
zoo_89_792	83	153	792	5.73	48	0.94	49	65.54	0.02	69	0.01	0.30	69	0.01	0.30	78.2	0.16	0.39
zoo_90_1188	83	156	1188	5.62	48	0.79	50	120.56	0.04	64	0.02	0.25	63	0.02	0.24	80.1	0.22	0.40
zoo_90_1584	88	172	1584	5.70	56	2.27	57	192.32	0.02	70	0.02	0.20	69	0.03	0.19	92.2	0.31	0.39
zoo_90_1980	90	174	1980	5.77	56	2.05	56	441.30	0.00	66	0.03	0.15	66	0.03	0.15	94.6	0.39	0.41
zoo_95_433	83	145	433	6.26	47	0.43	49	37.68	0.04	59	0.01	0.20	58	0.01	0.19	71.2	0.12	0.34
zoo_95_865	84	146	865	6.87	41	1.14	42	69.60	0.02	58	0.02	0.29	59	0.02	0.31	71.6	0.18	0.43
zoo_95_904	90	135	904	5.72	44	1.09	44	61.45	0.00	53	0.01	0.17	53	0.02	0.17	66.3	0.15	0.34
zoo_95_1297	87	154	1297	6.94	45	2.24	46	584.03	0.02	56	0.03	0.20	57	0.03	0.21	75.7	0.27	0.41

Instance Name	$\lvert D\rvert$	$\lvert I\rvert$	$\lvert F\rvert$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_95_1729	92	160	1729	7.10	48	4.09	48	252.92	0.00	57	0.03	0.16	57	0.04	0.16	81.1	0.34	0.41
zoo_96_396	78	117	396	5.45	40	0.19	41	4.36	0.02	47	0.01	0.15	49	0.01	0.18	57.2	0.07	0.30
zoo_96_452	82	143	452	5.87	50	0.34	52	12.26	0.04	61	0.01	0.18	61	0.01	0.18	73.3	0.11	0.32
zoo_96_792	82	131	792	5.95	45	0.47	45	33.63	0.00	55	0.01	0.18	57	0.01	0.21	66.9	0.13	0.33
zoo_96_903	91	163	903	5.98	53	1.00	54	50.53	0.02	71	0.01	0.25	67	0.02	0.21	83.0	0.19	0.36
zoo_96_1188	84	135	1188	5.90	43	0.82	44	70.03	0.02	52	0.02	0.17	52	0.02	0.17	69.2	0.19	0.38
zoo_96_1354	91	143	1354	5.89	43	1.77	43	128.77	0.00	58	0.02	0.26	58	0.02	0.26	74.9	0.23	0.43
zoo_96_1355	89	161	1355	6.09	48	2.36	48	388.08	0.00	64	0.02	0.25	64	0.02	0.25	81.3	0.25	0.41
zoo_96_1585	88	144	1585	6.28	47	1.30	47	143.23	0.00	53	0.03	0.11	53	0.03	0.11	73.1	0.25	0.36
zoo_96_1806	95	176	1806	6.15	54	3.61	54	160.11	0.00	68	0.03	0.21	68	0.03	0.21	92.8	0.36	0.42
zoo_96_1807	95	150	1807	6.21	47	1.43	47	20.63	0.00	54	0.03	0.13	54	0.03	0.13	76.8	0.29	0.39
zoo_96_1980	90	146	1980	6.32	48	1.99	48	105.87	0.00	55	0.04	0.13	55	0.04	0.13	76.4	0.31	0.37
zoo_96_2256	96	153	2256	6.21	48	4.02	48	36.57	0.00	53	0.04	0.09	53	0.04	0.09	77.8	0.36	0.38
zoo_98_471	84	178	471	3.46	70	0.25	70	2.35	0.00	85	0.00	0.18	86	0.00	0.19	97.0	0.11	0.28
zoo_98_942	95	206	942	3.99	70	0.63	70	36.78	0.00	95	0.02	0.26	92	0.01	0.24	109.3	0.22	0.36
zoo_98_1412	96	214	1412	4.05	73	1.69	73	129.58	0.00	95	0.01	0.23	96	0.01	0.24	113.3	0.31	0.36
zoo_98_1881	98	216	1881	4.18	73	2.52	73	330.38	0.00	88	0.02	0.17	88	0.02	0.17	112.4	0.39	0.35
zoo_98_2352	98	218	2352	4.29	73	3.50	73	700.84	0.00	89	0.03	0.18	89	0.03	0.18	111.8	0.47	0.35

Instance Name	$\lvert D\rvert$	$\lvert I\rvert$	$\lvert F\rvert$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_99_491	92	161	491	4.72	58	0.37	59	5.01	0.02	74	0.02	0.22	71	0.01	0.18	80.5	0.11	0.28
zoo_100_980	92	169	980	5.19	51	1.09	52	56.58	0.02	69	0.01	0.26	69	0.01	0.26	87.4	0.19	0.42
zoo_100_1470	99	184	1470	5.38	57	2.42	57	744.07	0.00	76	0.02	0.25	77	0.02	0.26	94.2	0.28	0.39
zoo_100_1960	99	183	1960	5.27	55	1.70	55	3603.06	0.00	72	0.03	0.24	71	0.03	0.23	93.9	0.34	0.41
zoo_100_2450	100	187	2450	5.36	57	4.18	57	3600.77	0.00	70	0.04	0.19	70	0.04	0.19	98.0	0.44	0.42
zoo_101_510	87	151	510	5.25	46	0.55	49	47.14	0.06	63	0.01	0.27	61	0.01	0.25	72.4	0.10	0.36
zoo_102_510	97	141	510	4.00	69	0.23	69	2.01	0.00	74	0.01	0.07	73	0.01	0.05	80.2	0.09	0.14
zoo_102_1020	97	174	1020	5.58	52	1.20	54	144.91	0.04	69	0.02	0.25	69	0.02	0.25	85.9	0.21	0.39
zoo_102_1530	98	172	1530	5.82	49	2.57	49	571.65	0.00	65	0.02	0.25	64	0.03	0.23	84.6	0.27	0.42
zoo_102_2041	102	177	2041	5.68	55	1.78	55	125.71	0.00	70	0.03	0.21	70	0.04	0.21	89.1	0.36	0.38
zoo_102_2044	101	154	2044	4.72	55	1.60	55	1115.91	0.00	60	0.03	0.08	60	0.03	0.08	85.4	0.30	0.36
zoo_102_2550	102	180	2550	5.89	55	5.65	55	309.57	0.00	65	0.04	0.15	65	0.05	0.15	93.0	0.51	0.41
zoo_104_531	101	167	531	3.53	70	0.28	70	3.43	0.00	82	0.00	0.15	78	0.00	0.10	90.8	0.11	0.23
zoo_104_1061	100	168	1061	3.77	60	0.60	60	12.68	0.00	74	0.01	0.19	73	0.01	0.18	90.7	0.19	0.34
zoo_104_1592	104	179	1592	3.89	55	1.06	55	196.70	0.00	77	0.01	0.29	76	0.02	0.28	91.2	0.25	0.40
zoo_104_2121	104	179	2121	3.97	56	2.05	56	43.04	0.00	68	0.04	0.18	68	0.02	0.18	91.4	0.33	0.39
zoo_104_2652	104	179	2652	4.05	55	1.85	55	55.67	0.00	61	0.03	0.10	61	0.03	0.10	92.2	0.42	0.40
zoo_106_552	90	168	552	4.70	64	0.33	65	4.95	0.02	77	0.01	0.17	76	0.01	0.16	90.2	0.14	0.29

Instance Name	$\|D\|$	$\|I\|$	$\|F\|$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_106_1103	99	206	1103	4.99	70	1.11	70	146.03	0.00	90	0.01	0.22	86	0.02	0.19	110.0	0.30	0.36
zoo_106_1654	101	218	1654	5.14	68	2.84	68	268.45	0.00	95	0.02	0.28	93	0.02	0.27	117.7	0.45	0.42
zoo_106_1655	104	181	1655	4.71	59	1.61	59	208.87	0.00	73	0.02	0.19	73	0.04	0.19	98.7	0.34	0.40
zoo_106_2205	105	230	2205	5.17	74	4.12	74	3036.33	0.00	96	0.03	0.23	96	0.04	0.23	125.1	0.56	0.41
zoo_106_2206	104	181	2206	4.81	58	3.06	58	155.76	0.00	68	0.03	0.15	68	0.03	0.15	97.3	0.42	0.40
zoo_106_2756	106	232	2756	5.25	73	6.94	73	871.70	0.00	95	0.04	0.23	95	0.04	0.23	126.5	0.69	0.42
zoo_108_573	100	168	573	3.59	67	0.32	67	13.80	0.00	76	0.01	0.12	75	0.01	0.11	89.1	0.11	0.25
zoo_108_1145	108	189	1145	3.97	66	0.72	66	17.45	0.00	81	0.01	0.19	81	0.01	0.19	98.0	0.25	0.33
zoo_108_1146	104	185	1146	3.93	63	0.73	63	22.60	0.00	77	0.01	0.18	79	0.01	0.20	96.5	0.21	0.35
zoo_108_1717	108	191	1717	4.18	61	2.25	61	103.71	0.00	77	0.02	0.21	77	0.02	0.21	99.3	0.31	0.39
zoo_108_1718	108	189	1718	4.22	61	1.29	61	210.35	0.00	79	0.02	0.23	79	0.02	0.23	97.3	0.32	0.37
zoo_108_2289	108	190	2289	4.38	58	2.96	58	3600.55	0.00	69	0.03	0.16	69	0.03	0.16	98.0	0.39	0.41
zoo_108_2290	108	191	2290	4.39	58	2.76	58	3600.14	0.00	69	0.03	0.16	69	0.03	0.16	98.0	0.40	0.41
zoo_108_2862	108	191	2862	4.55	58	4.53	58	1721.64	0.00	65	0.03	0.11	65	0.03	0.11	97.4	0.50	0.40
zoo_109_594	103	175	594	3.69	75	0.33	75	3.22	0.00	89	0.01	0.16	82	0.01	0.09	96.1	0.13	0.22
zoo_110_594	106	180	594	3.66	73	0.35	73	3.64	0.00	82	0.01	0.11	79	0.01	0.08	94.8	0.13	0.23
zoo_110_595	96	174	595	6.37	60	0.61	60	12.01	0.00	71	0.01	0.15	69	0.01	0.13	87.8	0.17	0.32
zoo_110_1188	109	190	1188	3.93	67	0.80	67	23.20	0.00	79	0.01	0.15	79	0.01	0.15	99.7	0.23	0.33

Instance Name	$\lvert D\rvert$	$\lvert I\rvert$	$\lvert F\rvert$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
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zoo_110_1189	100	198	1189	6.52	61	1.18	62	359.98	0.02	81	0.02	0.25	77	0.02	0.21	100.1	0.32	0.39
zoo_110_1782	107	210	1782	6.62	67	2.80	68	3607.23	0.01	82	0.03	0.18	80	0.04	0.16	111.3	0.46	0.40
zoo_110_1783	109	191	1783	4.18	63	1.81	63	206.28	0.00	75	0.02	0.16	75	0.02	0.16	98.8	0.33	0.36
zoo_110_2376	106	212	2376	6.70	64	5.60	64	3603.79	0.00	86	0.04	0.26	83	0.05	0.23	112.4	0.57	0.43
zoo_110_2380	110	194	2380	4.39	59	3.36	59	1566.30	0.00	70	0.03	0.16	70	0.03	0.16	99.6	0.41	0.41
zoo_110_2970	110	218	2970	6.87	66	7.85	66	2522.01	0.00	85	0.06	0.22	84	0.06	0.21	115.8	0.71	0.43
zoo_111_616	101	176	616	3.72	73	0.33	73	5.14	0.00	87	0.01	0.16	84	0.01	0.13	95.1	0.13	0.23
zoo_112_616	110	180	616	3.65	76	0.37	76	6.88	0.00	85	0.01	0.11	83	0.01	0.08	97.2	0.14	0.22
zoo_112_1232	112	196	1232	3.93	76	0.80	76	19.20	0.00	90	0.01	0.16	89	0.01	0.15	103.5	0.24	0.27
zoo_112_1848	112	195	1848	4.24	61	1.37	61	213.02	0.00	78	0.02	0.22	78	0.02	0.22	101.2	0.34	0.40
zoo_112_2464	111	195	2464	4.44	59	3.29	59	162.47	0.00	70	0.03	0.16	70	0.03	0.16	98.8	0.43	0.40
zoo_112_2465	112	197	2465	4.36	60	1.92	60	141.39	0.00	73	0.03	0.18	73	0.03	0.18	102.4	0.44	0.41
zoo_112_3080	112	197	3080	4.55	60	2.46	60	730.45	0.00	69	0.03	0.13	69	0.04	0.13	99.6	0.52	0.40
zoo_114_639	108	185	639	3.70	79	0.35	79	3.00	0.00	94	0.01	0.16	90	0.01	0.12	100.8	0.14	0.22
zoo_114_1278	114	199	1278	4.04	71	0.95	71	72.51	0.00	84	0.01	0.15	84	0.01	0.15	107.1	0.27	0.34
zoo_114_1916	111	194	1916	4.30	59	1.79	59	128.97	0.00	73	0.02	0.19	71	0.02	0.17	101.6	0.36	0.42
zoo_114_2553	114	200	2553	4.48	62	3.52	62	3601.87	0.00	74	0.03	0.16	74	0.03	0.16	102.7	0.47	0.40
zoo_114_3192	114	200	3192	4.61	61	5.35	61	1762.97	0.00	70	0.06	0.13	70	0.04	0.13	102.9	0.57	0.41

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					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_116_662	108	185	662	3.64	74	0.36	74	4.70	0.00	91	0.01	0.19	88	0.01	0.16	100.2	0.15	0.26
zoo_116_1323	116	202	1323	4.13	74	1.05	74	23.20	0.00	91	0.02	0.19	88	0.01	0.16	106.6	0.28	0.31
zoo_116_1984	115	200	1984	4.37	63	2.52	63	449.96	0.00	79	0.02	0.20	77	0.02	0.18	105.0	0.38	0.40
zoo_116_2645	115	229	2645	4.13	71	4.19	71	1820.01	0.00	93	0.03	0.24	93	0.03	0.24	120.0	0.55	0.41
zoo_116_2646	116	202	2646	4.51	62	4.34	62	217.42	0.00	70	0.03	0.11	69	0.04	0.10	106.9	0.50	0.42
zoo_116_3306	116	203	3306	4.62	62	3.75	62	2485.19	0.00	72	0.04	0.14	72	0.04	0.14	104.6	0.59	0.41
zoo_117_685	112	193	685	3.83	76	0.48	77	8.36	0.01	88	0.01	0.14	88	0.01	0.14	103.6	0.16	0.27
zoo_117_1370	113	195	1370	4.13	67	1.28	67	49.33	0.00	80	0.02	0.16	83	0.01	0.19	101.4	0.27	0.34
zoo_118_685	111	188	685	3.91	76	0.48	76	3.54	0.00	88	0.01	0.14	87	0.01	0.13	102.6	0.15	0.26
zoo_118_1369	116	203	1369	4.16	70	1.71	70	56.58	0.00	84	0.01	0.17	84	0.02	0.17	108.9	0.28	0.36
zoo_118_1370	117	203	1370	4.09	72	1.29	72	35.37	0.00	90	0.01	0.20	89	0.01	0.19	108.7	0.28	0.34
zoo_118_2053	117	205	2053	4.34	65	2.02	65	3600.24	0.00	83	0.04	0.22	83	0.02	0.22	106.2	0.39	0.39
zoo_118_2054	116	202	2054	4.33	64	3.05	64	196.69	0.00	77	0.02	0.17	77	0.02	0.17	107.5	0.40	0.40
zoo_118_2737	117	205	2737	4.44	63	4.35	63	3600.52	0.00	72	0.03	0.13	72	0.03	0.13	107.8	0.51	0.42
zoo_118_2738	118	208	2738	4.50	64	2.41	64	3600.88	0.00	71	0.03	0.10	71	0.03	0.10	109.1	0.52	0.41
zoo_118_3422	118	208	3422	4.60	64	5.41	64	3628.76	0.00	73	0.04	0.12	73	0.04	0.12	109.0	0.63	0.41
zoo_120_2833	120	209	2833	4.47	66	2.22	66	1075.36	0.00	82	0.03	0.20	82	0.03	0.20	108.6	0.53	0.39
zoo_120_3540	120	209	3540	4.61	65	2.97	65	3600.78	0.00	74	0.04	0.12	74	0.04	0.12	107.8	0.64	0.40

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zoo_121_2929	119	206	2929	4.49	63	4.87	63	2517.97	0.00	76	0.03	0.17	76	0.04	0.17	105.9	0.54	0.41
zoo_122_732	116	189	732	3.76	76	0.48	76	4.24	0.00	89	0.02	0.15	88	0.01	0.14	101.4	0.16	0.25
zoo_122_1464	115	208	1464	6.88	57	1.59	59	1691.09	0.03	85	0.03	0.33	77	0.03	0.26	101.7	0.38	0.44
zoo_122_2196	122	211	2196	4.36	69	1.62	69	495.73	0.00	87	0.02	0.21	84	0.03	0.18	113.9	0.45	0.39
zoo_122_2197	122	212	2197	4.32	68	3.09	68	3578.52	0.00	90	0.03	0.24	91	0.03	0.25	110.6	0.43	0.39
zoo_122_2930	121	210	2930	4.49	65	4.33	65	3044.50	0.00	78	0.04	0.17	78	0.04	0.17	110.6	0.56	0.41
zoo_122_3660	122	212	3660	4.62	66	3.27	66	3617.53	0.00	76	0.05	0.13	76	0.05	0.13	112.1	0.70	0.41
zoo_123_732	105	191	732	6.70	52	1.24	55	563.60	0.05	73	0.01	0.29	70	0.01	0.26	87.2	0.24	0.40
zoo_123_2196	115	209	2196	7.03	56	5.43	57	3600.25	0.02	82	0.05	0.32	82	0.05	0.32	99.2	0.49	0.44
zoo_123_2929	121	216	2929	7.01	61	7.68	61	1288.10	0.00	79	0.06	0.23	78	0.06	0.22	105.2	0.66	0.42
zoo_123_3660	122	218	3660	7.03	61	8.50	61	281.96	0.00	81	0.07	0.25	81	0.08	0.25	108.1	0.86	0.44
zoo_124_757	120	179	757	3.59	90	0.41	90	3.68	0.00	98	0.01	0.08	97	0.01	0.07	106.5	0.16	0.15
zoo_124_1513	121	179	1513	3.96	74	1.03	74	123.32	0.00	81	0.01	0.09	81	0.02	0.09	102.2	0.27	0.28
zoo_124_2269	123	183	2269	4.15	64	2.19	64	3600.88	0.00	82	0.03	0.22	82	0.02	0.22	102.4	0.39	0.38
zoo_124_3025	124	187	3025	4.25	63	2.21	63	106.45	0.00	70	0.04	0.10	70	0.03	0.10	105.0	0.52	0.40
zoo_124_3782	124	187	3782	4.28	63	3.32	63	129.52	0.00	63	0.04	0.00	63	0.04	0.00	103.2	0.65	0.39
zoo_129_833	125	200	833	4.12	88	0.70	88	35.53	0.00	95	0.01	0.07	94	0.01	0.06	112.2	0.20	0.22
zoo_129_3332	128	215	3332	4.69	73	5.81	73	391.57	0.00	84	0.04	0.13	84	0.04	0.13	121.3	0.69	0.40

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zoo_130_1665	128	208	1665	4.32	81	1.32	81	128.42	0.00	95	0.02	0.15	95	0.02	0.15	117.6	0.36	0.31
zoo_130_2496	128	214	2496	4.55	76	2.60	76	124.29	0.00	88	0.03	0.14	88	0.03	0.14	119.1	0.52	0.36
zoo_130_4160	130	220	4160	4.78	74	4.71	74	1315.09	0.00	78	0.06	0.05	78	0.06	0.05	123.3	0.86	0.40
zoo_131_1716	124	199	1716	4.26	65	1.40	65	223.43	0.00	83	0.02	0.22	83	0.02	0.22	102.6	0.32	0.37
zoo_132_858	120	192	858	3.86	89	0.50	89	8.62	0.00	93	0.01	0.04	93	0.01	0.04	104.6	0.20	0.15
zoo_132_2574	130	217	2574	4.39	66	6.05	68	3604.78	0.03	78	0.03	0.15	78	0.03	0.15	112.2	0.50	0.41
zoo_132_3432	130	217	3432	4.51	65	6.10	65	293.07	0.00	73	0.04	0.11	73	0.04	0.11	110.4	0.64	0.41
zoo_132_4290	132	221	4290	4.60	67	4.86	67	198.75	0.00	73	0.05	0.08	73	0.06	0.08	114.2	0.83	0.41
zoo_134_885	114	203	885	6.58	65	1.17	66	224.24	0.02	85	0.02	0.24	79	0.02	0.18	98.7	0.28	0.34
zoo_134_1769	118	207	1769	6.79	57	3.55	58	1148.57	0.02	78	0.03	0.27	76	0.04	0.25	101.0	0.43	0.44
zoo_134_2653	127	221	2653	7.08	67	6.82	68	683.15	0.01	81	0.05	0.17	81	0.06	0.17	110.3	0.64	0.39
zoo_134_3542	133	233	3542	7.15	68	12.28	68	1589.69	0.00	83	0.07	0.18	83	0.08	0.18	117.8	0.88	0.42
zoo_134_4422	134	234	4422	7.23	69	12.29	69	551.15	0.00	84	0.09	0.18	84	0.10	0.18	116.8	1.07	0.41
zoo_136_912	120	191	912	4.55	73	0.77	73	19.68	0.00	82	0.01	0.11	82	0.01	0.11	96.9	0.20	0.25
zoo_136_1823	133	221	1823	4.95	75	2.85	77	748.24	0.03	95	0.02	0.21	95	0.03	0.21	116.8	0.43	0.36
zoo_136_2734	131	216	2734	5.07	67	4.71	67	3602.92	0.00	84	0.04	0.20	84	0.04	0.20	112.4	0.56	0.40
zoo_136_3645	136	226	3645	5.20	69	7.37	69	1120.03	0.00	79	0.05	0.13	79	0.05	0.13	118.3	0.76	0.42
zoo_136_4556	136	227	4556	5.32	68	9.50	68	325.93	0.00	78	0.06	0.13	78	0.07	0.13	118.6	0.94	0.43

Instance Name	$\|D\|$	$\|I\|$	$\|F\|$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_137_939	129	231	939	4.03	90	0.68	91	7.98	0.01	108	0.01	0.17	100	0.01	0.10	117.0	0.25	0.23
zoo_138_948	134	206	948	4.67	91	0.67	91	8.57	0.00	105	0.01	0.13	106	0.01	0.14	114.2	0.23	0.20
zoo_138_1877	135	252	1877	4.48	80	2.97	80	116.85	0.00	111	0.03	0.28	111	0.02	0.28	128.7	0.47	0.38
zoo_138_1879	137	210	1879	4.96	84	1.47	84	143.86	0.00	99	0.02	0.15	99	0.02	0.15	113.9	0.40	0.26
zoo_138_2817	138	262	2817	4.83	73	4.92	73	3150.09	0.00	102	0.04	0.28	102	0.04	0.28	131.3	0.73	0.44
zoo_138_2841	137	213	2841	4.98	72	4.30	72	216.54	0.00	87	0.04	0.17	90	0.04	0.20	112.2	0.59	0.36
zoo_138_3755	138	262	3755	5.07	70	9.52	70	2735.88	0.00	93	0.05	0.25	93	0.05	0.25	131.5	0.92	0.47
zoo_138_3823	138	216	3823	5.03	74	6.37	74	95.14	0.00	84	0.05	0.12	84	0.05	0.12	114.0	0.76	0.35
zoo_138_4692	138	262	4692	5.25	70	9.95	70	3600.45	0.00	90	0.06	0.22	90	0.07	0.22	131.8	1.09	0.47
zoo_140_966	108	190	966	7.37	50	1.25	53	1073.41	0.06	71	0.02	0.30	67	0.02	0.25	88.0	0.27	0.43
zoo_140_1933	125	215	1933	7.69	62	4.61	64	3600.17	0.03	87	0.04	0.29	86	0.05	0.28	102.9	0.54	0.40
zoo_140_2898	129	225	2898	8.06	61	7.84	61	1935.73	0.00	82	0.07	0.26	82	0.07	0.26	108.0	0.76	0.44
zoo_140_3864	140	241	3864	8.18	72	9.87	72	1704.57	0.00	91	0.10	0.21	90	0.10	0.20	119.1	1.04	0.40
zoo_140_4830	140	241	4830	8.24	71	16.42	71	3619.78	0.00	89	0.12	0.20	89	0.13	0.20	120.2	1.25	0.41
zoo_144_994	141	198	994	3.99	93	0.59	93	6.08	0.00	103	0.01	0.10	103	0.01	0.10	109.5	0.21	0.15
zoo_144_1989	139	202	1989	4.16	84	2.09	84	3600.09	0.00	94	0.02	0.11	92	0.02	0.09	111.5	0.38	0.25
zoo_144_2983	141	208	2983	4.38	72	3.75	72	3602.19	0.00	87	0.03	0.17	85	0.03	0.15	112.5	0.56	0.36
zoo_144_3988	142	212	3988	4.45	72	5.88	72	3600.34	0.00	81	0.04	0.11	81	0.05	0.11	115.6	0.75	0.38

Instance Name	$\vert D\vert$	$\vert I\vert$	$\vert F\vert$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_144_4970	142	212	4970	4.49	71	4.90	71	54.72	0.00	71	0.06	0.00	71	0.06	0.00	115.8	0.92	0.39
zoo_146_994	126	245	994	4.17	89	0.85	89	13.40	0.00	111	0.01	0.20	109	0.01	0.18	127.3	0.27	0.30
zoo_146_1052	117	210	1052	6.60	60	1.83	61	328.23	0.02	80	0.02	0.25	77	0.02	0.22	99.3	0.29	0.40
zoo_146_1988	138	279	1988	4.40	88	2.02	89	132.12	0.01	121	0.02	0.27	120	0.02	0.27	144.3	0.55	0.39
zoo_146_2982	140	289	2982	4.58	85	6.23	86	3600.31	0.01	121	0.03	0.30	114	0.04	0.25	153.6	0.82	0.45
zoo_146_3979	141	300	3979	4.67	89	9.03	89	3600.32	0.00	124	0.05	0.28	123	0.05	0.28	158.9	1.10	0.44
zoo_146_4970	142	302	4970	4.78	89	10.88	90	3600.63	0.01	116	0.07	0.23	115	0.07	0.23	159.4	1.34	0.44
zoo_147_1081	132	214	1081	6.37	68	1.34	72	624.94	0.06	90	0.02	0.24	90	0.02	0.24	105.5	0.33	0.36
zoo_148_1081	143	252	1081	4.49	94	0.96	96	52.73	0.02	115	0.01	0.18	114	0.01	0.18	131.3	0.35	0.28
zoo_148_2161	146	268	2161	4.77	85	3.97	86	771.15	0.01	117	0.03	0.27	113	0.03	0.25	138.9	0.63	0.39
zoo_148_3241	145	216	3241	12.68	72	5.57	75	3600.40	0.04	83	0.16	0.13	85	0.17	0.15	109.4	1.27	0.34
zoo_148_3242	148	276	3242	5.15	80	8.02	81	3600.44	0.01	105	0.05	0.24	105	0.04	0.24	142.3	0.87	0.44
zoo_148_4321	148	277	4321	5.43	77	9.74	78	3600.37	0.01	100	0.07	0.23	100	0.07	0.23	144.5	1.13	0.47
zoo_148_5402	148	277	5402	5.58	75	19.02	76	3601.47	0.01	94	0.09	0.20	94	0.08	0.20	143.6	1.38	0.48
zoo_164_1329	164	245	1329	3.23	123	0.91	123	15.78	0.00	136	0.01	0.10	136	0.01	0.10	144.2	0.32	0.15
zoo_164_2657	164	246	2657	3.35	102	2.29	102	9.68	0.00	117	0.02	0.13	117	0.03	0.13	133.3	0.54	0.23
zoo_164_3994	163	245	3994	3.41	88	3.32	88	3601.45	0.00	111	0.03	0.21	110	0.04	0.20	130.6	0.77	0.33
zoo_164_5317	164	247	5317	3.42	82	4.89	82	87.72	0.00	97	0.05	0.15	97	0.05	0.15	125.9	0.96	0.35

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					Sol	Time	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap	Sol	Time	Gap
zoo_164_6642	164	247	6642	3.44	82	7.17	82	67.04	0.00	82	0.05	0.00	82	0.06	0.00	124.4	1.19	0.34
zoo_166_2792	147	243	2792	10.87	69	6.70	70	3600.24	0.01	89	0.10	0.22	89	0.11	0.22	111.7	1.01	0.38
zoo_168_1395	154	251	1395	10.67	75	2.31	77	1303.12	0.03	96	0.05	0.22	95	0.06	0.21	117.9	0.74	0.36
zoo_168_4191	161	261	4191	11.42	79	11.76	80	1321.66	0.01	103	0.17	0.23	103	0.18	0.23	127.0	1.58	0.38
zoo_168_5580	167	269	5580	11.40	85	30.05	85	723.75	0.00	100	0.23	0.15	99	0.25	0.14	130.9	2.01	0.35
zoo_168_6972	168	271	6972	11.59	86	34.81	86	1057.66	0.00	100	0.30	0.14	100	0.30	0.14	133.0	2.48	0.35
zoo_176_1362	146	236	1362	7.12	76	2.53	79	223.67	0.04	100	0.03	0.24	100	0.03	0.24	116.0	0.43	0.34
zoo_176_1534	149	243	1534	13.77	62	6.45	67	3600.65	0.07	80	0.08	0.23	81	0.08	0.23	100.4	0.93	0.38
zoo_176_2723	156	262	2723	7.17	85	6.10	86	1127.84	0.01	107	0.06	0.21	107	0.06	0.21	135.4	0.82	0.37
zoo_176_3067	165	260	3067	13.63	77	7.77	78	718.40	0.01	89	0.16	0.13	93	0.18	0.17	115.7	1.48	0.33
zoo_176_4085	162	274	4085	7.37	83	10.09	83	154.92	0.00	108	0.08	0.23	108	0.09	0.23	142.8	1.22	0.42
zoo_176_4597	166	263	4597	13.55	78	26.22	79	1243.14	0.01	91	0.24	0.14	91	0.26	0.14	118.9	1.92	0.34
zoo_176_5445	165	281	5445	7.45	88	17.19	88	1033.17	0.00	104	0.12	0.15	103	0.13	0.15	147.5	1.63	0.40
zoo_176_6127	174	271	6127	13.79	86	21.47	86	676.94	0.00	98	0.35	0.12	98	0.34	0.12	127.0	2.54	0.32
zoo_176_6806	166	282	6806	7.52	88	27.14	88	711.51	0.00	99	0.15	0.11	99	0.15	0.11	144.9	1.94	0.39
zoo_176_7656	176	273	7656	13.90	88	54.26	88	541.42	0.00	106	0.41	0.17	106	0.44	0.17	128.8	3.03	0.32
zoo_183_1675	158	258	1675	13.72	67	6.42	73	3600.18	0.08	90	0.09	0.26	89	0.09	0.25	107.1	1.13	0.37
zoo_183_6703	179	280	6703	14.20	87	53.84	87	1527.59	0.00	104	0.38	0.16	104	0.41	0.16	128.5	2.78	0.32

Instance Name	$\|D\|$	$\|I\|$	$\|F\|$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
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zoo_184_3349	171	270	3349	14.12	79	8.72	80	1131.66	0.01	95	0.18	0.17	95	0.19	0.17	120.2	1.74	0.34
zoo_184_5023	172	273	5023	14.15	80	29.51	80	1724.93	0.00	94	0.28	0.15	94	0.28	0.15	120.9	2.16	0.34
zoo_184_8372	184	285	8372	14.07	92	51.33	92	962.58	0.00	110	0.47	0.16	110	0.47	0.16	133.2	3.45	0.31
zoo_220_2398	185	341	2398	7.82	99	6.68	107	3600.28	0.07	135	0.05	0.27	134	0.06	0.26	164.1	1.10	0.40
zoo_220_4798	208	374	4798	8.27	113	10.03	113	3600.54	0.00	153	0.12	0.26	147	0.13	0.23	188.0	2.13	0.40
zoo_220_7197	210	381	7197	8.24	111	35.44	115	3602.64	0.03	149	0.18	0.26	146	0.20	0.24	195.4	3.04	0.43
zoo_220_9592	219	400	9592	8.51	122	52.58	123	3601.75	0.01	158	0.24	0.23	158	0.27	0.23	208.9	4.28	0.42
zoo_220_11990	220	403	11990	8.62	123	94.40	125	3604.59	0.02	150	0.31	0.18	149	0.34	0.17	211.2	5.27	0.42
zoo_224_2534	188	359	2534	7.12	105	6.77	109	3607.45	0.04	148	0.06	0.29	141	0.06	0.26	178.5	1.13	0.41
zoo_226_5064	214	410	5064	7.70	117	18.16	126	3600.69	0.07	160	0.12	0.27	154	0.13	0.24	207.2	2.36	0.44
zoo_226_7597	224	427	7597	7.94	124	41.56	127	3601.14	0.02	172	0.20	0.28	169	0.21	0.27	223.5	3.63	0.45
zoo_226_10128	223	432	10128	8.02	125	79.34	137	3651.21	0.09	162	0.26	0.23	158	0.27	0.21	226.3	4.74	0.45
zoo_226_12656	226	436	12656	8.16	129	108.15	135	3601.94	0.04	164	0.34	0.21	163	0.35	0.21	232.2	5.89	0.44
zoo_250_3103	217	369	3103	11.07	103	12.96	114	3600.36	0.10	136	0.12	0.24	136	0.13	0.24	169.1	1.89	0.39
zoo_250_6206	237	400	6206	11.19	116	38.53	120	3600.81	0.03	148	0.24	0.22	147	0.27	0.21	193.1	3.42	0.40
zoo_250_9312	243	410	9312	11.01	122	69.25	123	3601.10	0.01	150	0.35	0.19	150	0.38	0.19	200.2	4.74	0.39
zoo_250_12402	246	411	12402	11.00	125	101.82	125	3603.10	0.00	152	0.50	0.18	152	0.50	0.18	204.3	6.03	0.39
zoo_250_15500	250	418	15500	11.14	129	465.89	129	3602.22	0.00	153	0.62	0.16	152	0.64	0.15	207.3	7.62	0.38

Instance Name	$\|D\|$	$\|I\|$	$\|F\|$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
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zoo_254_3209	252	377	3209	4.99	186	4.63	187	3604.21	0.01	210	0.04	0.11	212	0.05	0.12	230.6	1.32	0.19
zoo_254_6424	251	380	6424	5.39	154	10.08	155	3602.56	0.01	186	0.10	0.17	188	0.10	0.18	230.6	2.52	0.33
zoo_254_9711	253	384	9711	5.47	142	15.94	142	3601.16	0.00	174	0.15	0.18	174	0.16	0.18	232.7	3.77	0.39
zoo_254_12830	253	384	12830	5.52	128	32.49	128	1388.26	0.00	152	0.20	0.16	152	0.20	0.16	228.3	4.80	0.44
zoo_254_16002	254	386	16002	5.55	127	76.99	127	1953.04	0.00	131	0.27	0.03	131	0.27	0.03	225.8	5.93	0.44
zoo_290_4180	254	458	4180	9.69	125	20.12	138	3600.60	0.09	180	0.14	0.31	175	0.15	0.29	213.1	2.50	0.41
zoo_290_8359	268	480	8359	10.51	133	54.36	142	3601.77	0.06	175	0.33	0.24	177	0.33	0.25	233.9	4.83	0.43
zoo_290_12533	282	502	12533	10.51	144	95.68	155	3602.86	0.07	193	0.50	0.25	189	0.49	0.24	247.6	7.33	0.42
zoo_290_16733	287	510	16733	10.78	150	197.95	159	3616.35	0.06	184	0.70	0.18	186	0.66	0.19	254.8	9.93	0.41
zoo_290_20880	290	518	20880	10.85	152	471.84	167	3804.75	0.09	183	0.83	0.17	183	0.85	0.17	260.9	12.58	0.42
zoo_298_4411	277	489	4411	9.32	147	37.31	161	3600.59	0.09	198	0.14	0.26	201	0.14	0.27	241.1	2.91	0.39
zoo_298_8842	285	506	8842	9.30	149	53.12	214	3601.07	0.30	203	0.30	0.27	198	0.29	0.25	258.3	5.22	0.42
zoo_298_13242	285	517	13242	9.65	150	156.30	163	3602.67	0.08	201	0.47	0.25	200	0.45	0.25	262.5	7.93	0.43
zoo_298_17653	293	529	17653	9.80	155	141.87	163	3602.50	0.05	200	0.59	0.23	198	0.60	0.22	271.2	10.59	0.43
zoo_298_22052	298	536	22052	9.83	161	372.87	165	3617.28	0.02	197	0.72	0.18	197	0.76	0.18	275.6	13.47	0.42
zoo_306_4666	285	459	4666	8.69	179	13.52	182	3600.74	0.02	211	0.14	0.15	210	0.14	0.15	248.2	2.80	0.28
zoo_306_9309	295	477	9309	8.98	166	40.47	174	3601.07	0.05	199	0.28	0.17	198	0.29	0.16	256.6	5.40	0.35
zoo_306_14006	305	499	14006	9.25	171	71.97	182	3602.66	0.06	203	0.41	0.16	204	0.44	0.16	272.2	8.24	0.37

Instance Name	$\|D\|$	$\|I\|$	$\|F\|$	Avg	Lower Bound		Cover			Heuristic			Alternate Sorting			Random		
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zoo_306_18706	302	500	18706	9.27	164	143.46	180	3603.44	0.09	192	0.57	0.15	195	0.60	0.16	271.3	11.02	0.40
zoo_306_23256	306	508	23256	9.35	167	235.46	177	3602.60	0.06	186	0.69	0.10	186	0.76	0.10	273.9	13.68	0.39
zoo_316_4973	267	456	4973	12.15	121	23.13	205	3600.90	0.41	173	0.23	0.30	171	0.24	0.29	211.3	3.36	0.43
zoo_316_9927	287	488	9927	12.38	135	68.92	487	3601.01	0.72	177	0.47	0.24	174	0.49	0.22	233.5	6.30	0.42
zoo_316_14934	301	512	14934	12.97	152	117.88	159	3602.33	0.04	193	0.73	0.21	191	0.77	0.20	250.0	9.80	0.39
zoo_316_19883	311	526	19883	13.04	158	382.30	177	3627.98	0.11	201	1.04	0.21	201	1.05	0.21	262.4	13.99	0.40
zoo_316_24806	316	537	24806	13.09	165	505.98	184	3622.90	0.10	199	1.29	0.17	199	1.35	0.17	271.0	17.19	0.39
zoo_317_3790	228	371	3790	12.68	103	21.26	112	3600.45	0.08	138	0.17	0.25	142	0.19	0.27	167.3	2.54	0.38
zoo_317_7571	249	406	7571	13.29	117	47.15	190	3601.03	0.38	147	0.41	0.20	145	0.42	0.19	191.8	4.55	0.39
zoo_317_11345	270	428	11345	13.59	136	107.77	137	1941.78	0.01	168	0.62	0.19	172	0.65	0.21	213.3	7.15	0.36
zoo_317_15150	271	434	15150	13.55	135	196.74	135	3633.09	0.00	161	0.82	0.16	159	0.83	0.15	215.0	8.94	0.37
zoo_317_18906	276	441	18906	13.74	140	352.52	141	3625.05	0.01	161	1.06	0.13	160	1.05	0.13	220.0	11.12	0.36
zoo_394_7736	361	603	7736	10.29	187	52.11	286	3601.03	0.35	245	0.28	0.24	236	0.30	0.21	296.1	6.16	0.37
zoo_394_15448	371	642	15448	11.20	187	123.48	641	3601.58	0.71	251	0.66	0.25	253	0.69	0.26	319.9	12.29	0.42
zoo_394_23194	382	665	23194	11.57	192	522.75	256	3615.34	0.25	250	0.98	0.23	247	1.04	0.22	334.5	19.25	0.43
zoo_394_30895	388	674	30895	11.39	198	1448.66	231	3660.49	0.14	238	1.30	0.17	240	1.32	0.18	340.1	25.04	0.42
zoo_394_38612	394	684	38612	11.51	-	-	-	-	-	244	1.61	0.00	244	1.66	0.00	345.8	31.73	0.00