

Train Benchmark Case: an EMF-INCQUERY Solution*

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This paper presents a solution for the Train Benchmark Case of the 2015 Transformation Tool Contest, using EMF-INCQUERY.

1 Introduction

This paper describes a solution for the TTC 2015 Train Benchmark Case. The source code of the solution is available as an open-source project.¹ There is also a SHARE image available.²

2 EMF-INCQUERY

Automated model transformations are frequently integrated to modeling environments, requiring both high performance and a concise programming interface to support software engineers. The objective of the EMF-INCQUERY [3, 5] framework is to provide a declarative way to define queries over EMF models. EMF-INCQUERY extended the pattern language of VIATRA2 with new features (including transitive closure, role navigation, match count) and tailored it to EMF models [4]. EMF-INCQUERY is developed with a focus on *incremental query evaluation*, however, the most recent version is also capable of evaluating queries with a *local search-based* algorithm.

2.1 Incremental Pattern Matching

EMF-INCQUERY uses the Rete algorithm [2] to perform incremental pattern matching. The Rete algorithm uses tuples to represent the model objects, attributes, references and partial matches in the model. The algorithm defines an asynchronous network of communicating nodes. The network consists of three types of nodes. Input nodes are responsible for indexing the model by type, i.e. they store the appropriate tuples for the objects and references. They are also responsible for producing the update messages and propagating them to the worker nodes. Worker nodes perform a transformation on the output of their parent node(s) and propagate the results. Partial query results are represented in tuples and stored in the memory of the worker node thus allowing for incremental query reevaluation. Production nodes are terminators that provide an interface for fetching the results of the query and the changes introduced by the latest transformation.

The incremental pattern matcher provides quick reevaluation for complex queries. However, it does so at the expense of high memory consumption as the partial results are stored in the Rete network.

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¹<https://github.com/FTSRG/trainbenchmark-ttc/tree/localsearch> (note that the solution is on the localsearch branch).

²http://is.ieis.tue.nl/staff/pvgorp/share/?page=ConfigureNewSession&vdi=ArchLinux64_TrainBenchmark-EIQ.vdi

2.2 Local Search-Based Pattern Matching

Local search-based pattern matching (LS) is commonly used in graph transformation tools [8, 6]. Along the incremental query engine, EMF-INCQUERY also provides a local search-based pattern matcher.

The matching process consists of four steps. (1) At first, in a preprocessing step the patterns are *normalized*: the constraint set is minimized, variables that are always equal are unified and positive pattern calls are flattened. These normalized patterns are evaluated by (2) the *query planner*, using a specified cost estimation function to provide search plans [11]: totally ordered lists of search operations used to ensure that the constraints from the pattern definition hold. From a single pattern specification multiple search plans can be derived, thus pattern matching includes (3) *plan selection* based on the input parameter binding and model-specific metrics. Finally, (4) *the search plan is executed* by a plan interpreter evaluating the different operations of the plans. If an operation fails, the interpreter backtracks; if all operations are executed successfully, a match is found.

Compared to the incremental query engine, the search-based algorithm requires less memory [10] and is therefore capable of evaluating performing queries on larger models if there is not enough memory available for the incremental engine.

2.3 Defining the Pattern Matching Strategy

Currently, the pattern matching strategy has to be determined by the developer by specifying the query backend of EMF-INCQUERY. Developing a hybrid pattern matching engine is subject to future work. This will allow the user to use annotations to define the evaluation strategy for each pattern. There are also plans to develop an adaptive query engine (Section 5).

2.4 Pattern Match Representation

For each query, EMF-INCQUERY defines a generates a set of utility classes. These classes store the model objects in the match and provide a convenient interface for reading and transforming the matches. These classes are used for implementing the transformation operations (Section A.1).

3 Solution

The case defines a well-formedness validation scenario set in the domain of railway systems [9]. The case provides a synthetic instance model generator which is capable of generating models of various sizes. For the solution, we used the metamodel defined in the case description without any modifications or extensions.

The solution was developed in the Eclipse IDE. For setting up the development environment, please refer to the readme file. The projects are not tied to the Eclipse environment and can be compiled with the Apache Maven [1] build automation tool. This offers a number of benefits, including portability and the possibility of continuous integration. The solution is written in Java 7. The patterns are defined in INCQUERY Pattern Language (IQPL) [4].

3.1 Example Query: RouteSensor

We describe the implementation of the RouteSensor query in detail. The other queries and transformations are implemented in a similar manner. The code of patterns and the transformation definitions are listed in Section A.1.

The RouteSensor query looks for sensors that are connected to a switch, but the sensor and the switch are not connected to the same route (Figure 1).

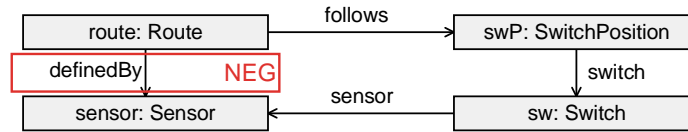


Figure 1: Pattern of the RouteSensor query.

The query in IQPL is listed in Listing 5. The positive conditions are defined by using the appropriate classes and references, while the negative application condition (NAC) is defined as a negative find operation (`neg find`) for a separate query.

```

1 pattern routeSensor(route, sensor, switchPosition, sw)
2 {
3   Route.follows(route, switchPosition);
4   SwitchPosition.^switch(switchPosition, sw);
5   TrackElement.sensor(sw, sensor);
6   neg find definedBy(route, sensor);
7 }
8
9 pattern definedBy(route, sensor)
10 {
11   Route.definedBy(route, sensor);
12 }

```

Listing 1: Pattern of the RouteSensor query.

During the repair operation, for the selected matches, the missing `definedBy` edge is inserted by connecting the route to the sensor. The Java transformation code implementing the transformation is listed in Listing 6. The transformation uses the match object returned by EMF-INCQUERY.

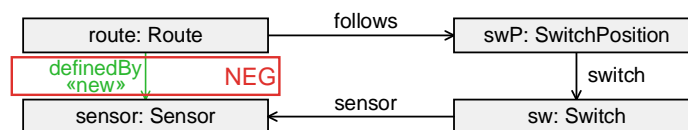


Figure 2: Transformation of the RouteSensor query.

```

1 public void transform(final Collection<Object> matches) {
2   for (final Object match : matches) {
3     final RouteSensorMatch rsm = (RouteSensorMatch) match;
4     rsm.getRoute().getDefinedBy().add(rsm.getSensor());
5   }
6 }

```

Listing 2: Transformation of the RouteSensor query.

3.2 Query Evaluation Strategies for the RouteSensor Pattern

We use the RouteSensor query to provide an overview of the various query evaluation strategies used in EMF-INCQUERY.

3.2.1 Incremental Evaluation

The Rete network derived from the RouteSensor query is shown in Figure 3. For the sake of clarity, we simplified the Rete network by removing some implementation-specific details. The evaluation in the Rete network starts with the *input nodes* (switch, follows, sensor, definedBy), these are indexing the model by collecting the appropriate tuples. The *worker nodes* are responsible for performing the relational operations, *join* and *antijoin* in this case. The join nodes have a pair of tuple masks (e.g. $\langle 2, 3 \rangle$ and $\langle 0, 1 \rangle$) to determine the attributes used in the join operation. The match set of the pattern is stored in the *production node*.

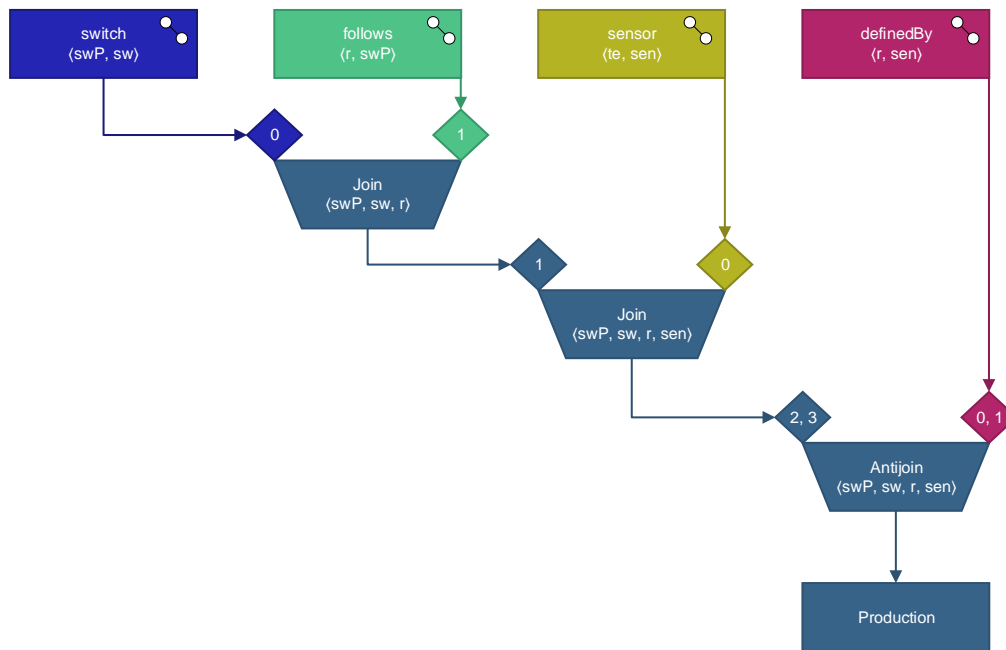


Figure 3: The Rete network for the RouteSensor query.

3.2.2 Local Search-Based Evaluation

The search plan generated for evaluating the RouteSensor query is shown in Figure 4. This screenshot is taken from the *Local Search Debugger* view of EMF-INCQUERY. The search plan is presented in the upper left part, while the found matches with the variable substitutions are shown below the search plan in a table viewer. The Zest-based graph viewer in the right visualises a match based on the selection of the table viewer.

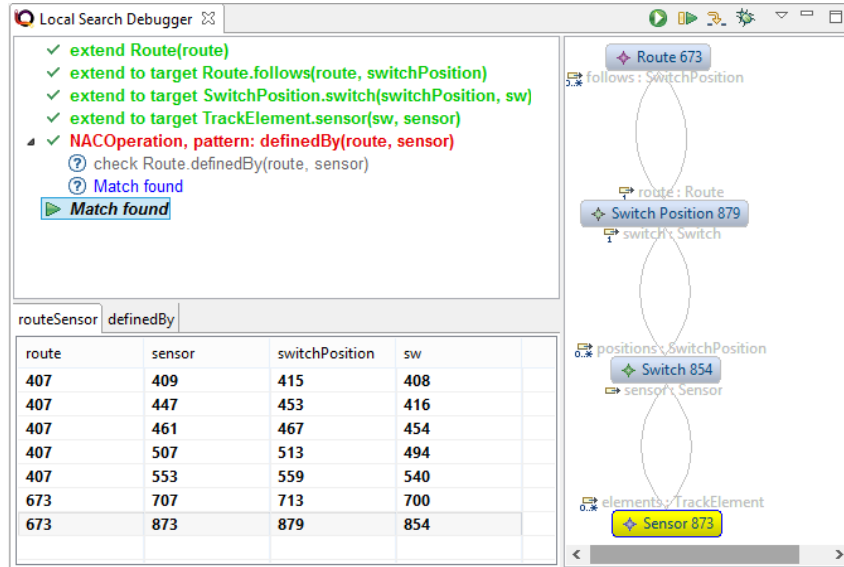


Figure 4: The search plan and the matches for the RouteSensor query.

4 Evaluation

In this section, we present the benchmark environment and evaluate the results. The detailed results are shown in Section A.2 (Table 1–Table 10).

4.1 Benchmark Environment

The benchmarks were performed on a 64-bit Ubuntu Server 14.04 virtual machine deployed on a private cloud. The machine used a quad-core 2.50 GHz Xeon L5420 processor and 16 GB of memory. We used Oracle JDK 8 and set the available heap memory to 15 GB.

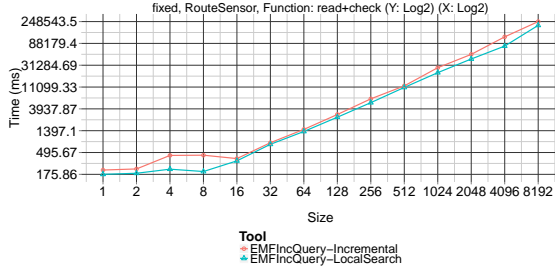
4.2 Benchmark Results

To present the results, we use the reporting framework of the Train Benchmark. The framework generates plots to visualise the execution time of the phases defined in the benchmark. The plots showing each query are included in Section A.2. On each plot, the x axis shows the problem size, i.e. the size of the instance model, while the y axis shows the aggregated execution time of a certain phases, measured in milliseconds. Both axes use logarithmic scale.

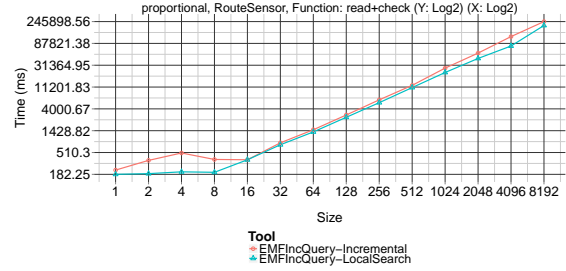
4.2.1 Benchmark Results for the RouteSensor Query

For the sake of conciseness, we only discuss the results for the RouteSensor query in detail.

The results for the *batch validation* are shown in Figure 5. The results that—given enough memory—both the incremental and the local search-based (LS) strategies are able to run the query and the transformation for the largest model. The *first validation* takes consistently longer for the incremental strategy as for the LS strategy. This is caused by the fact that the incremental strategy builds the Rete algorithm during the read phase. However, the difference is small as the *first validation* time largely consists of deserializing the EMF model.

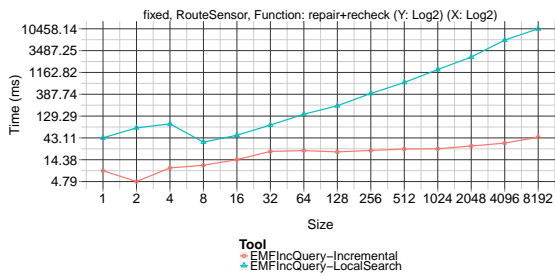


(a) Fixed change set

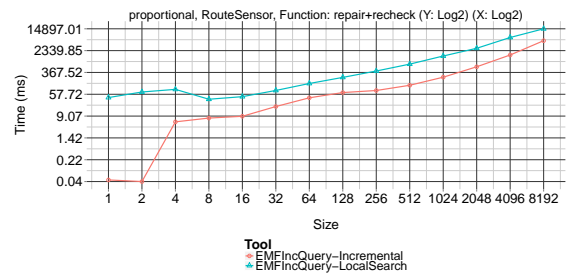


(b) Proportional change set

Figure 5: First validation times for the RouteSensor query.



(a) Fixed change set



(b) Proportional change set

Figure 6: Revalidation times for the RouteSensor query.

The execution times of the *revalidation* are shown in Figure 6. The execution time of the incremental strategy linearly correlates with the size of the change set. This implies that for a *fixed* change set, the incremental strategy is able to perform the transformation in constant time, while execution time for the LS strategy correlates with the model size. For the *proportional* change set, the revalidation time is a low-degree polynomial of the model size for both strategies, however, it is an order of magnitude faster for the incremental strategy than for the LS.

4.3 Comparison of the Query Evaluation Strategies

Section A.2 shows the detailed results for all queries and both evaluation strategies.

In the *first validation* (Figure 7 and Figure 9), the evaluation strategies show similar performance characteristics as both have to compute the complete result set of the query. The execution times for both strategies show that the most complex query is SemaphoreNeighbor, while the simplest one is SwitchSensor.

As expected, the execution times of the *revalidation* are different for the two strategies. Figure 8 shows that for the incremental strategy the execution time correlates with the size of the match set (instead of the model size). This can be observed when comparing the execution times for the *fixed* and the *proportional* change sets. Figure 10 shows that the execution time for the LS strategy is determined by the model size and is not affected by the size of the change set.

These results imply that the optimal evaluation strategy depends on the specific workload profile. If there is enough memory available and the transformations operate on a small amount of model elements, it is recommended to use the incremental strategy. If the transformations often change a large proportion of the model elements, the LS strategy is recommended.

5 Summary and Future Work

The paper presented a solution for the Train Benchmark case of the 2015 Transformation Tool Contest. The solution covers both the basic and the extension tasks.

There is ongoing work to develop a hybrid query engine [7] for EMF-INCQUERY. This will allow the user to use annotations on the patterns for specifying the desired query evaluation strategy. There are also plans to develop an adaptive query engine which will use query optimisation heuristics to determine the appropriate strategy based on the query, the model and the available resources.

Acknowledgements. The authors would like to thank Zoltán Ujhelyi for providing valuable insights into EMF-INCQUERY.

References

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- [11] Gergely Varró, Frederik Deckwerth, Martin Wieber & Andy Schürr (2012): *An Algorithm for Generating Model-Sensitive Search Plans for EMF Models*. In: *Theory and Practice of Model Transformations, LNCS 7307*, Springer, pp. 224–239, doi:10.1007/978-3-642-30476-7_15.

A Appendix

A.1 Patterns and Transformations

A.1.1 PosLength

```

1 pattern posLength(segment)
2 {
3   Segment.length(segment, length);
4   check(length <= 0);
5 }

```

Listing 3: Pattern of the PosLength query.

```

1 public void transform(final Collection<Object> matches) {
2   for (final Object match : matches) {
3     final RouteSensorMatch rsm = (RouteSensorMatch) match;
4     rsm.getRoute().getDefinedBy().add(rsm.getSensor());
5   }
6 }

```

Listing 4: Transformation of the PosLength query.

A.1.2 RouteSensor

```

1 pattern routeSensor(route, sensor, switchPosition, sw)
2 {
3   Route.follows(route, switchPosition);
4   SwitchPosition.^switch(switchPosition, sw);
5   TrackElement.sensor(sw, sensor);
6   neg find definedBy(route, sensor);
7 }
8
9 pattern definedBy(route, sensor)
10 {
11   Route.definedBy(route, sensor);
12 }

```

Listing 5: Pattern of the RouteSensor query.

```

1 public void transform(final Collection<Object> matches) {
2   for (final Object match : matches) {
3     final RouteSensorMatch rsm = (RouteSensorMatch) match;
4     rsm.getRoute().getDefinedBy().add(rsm.getSensor());
5   }
6 }

```

Listing 6: Transformation of the RouteSensor query.

A.1.3 SemaphoreNeighbor

```

1 pattern semaphoreNeighbor(semaphore, route1, route2, sensor1, sensor2, te1, te2)
2 {
3   Route.exit(route1, semaphore);
4   Route.definedBy(route1, sensor1);
5   TrackElement.sensor(te1, sensor1);
6   TrackElement.connectsTo(te1, te2);
7   TrackElement.sensor(te2, sensor2);
8   Route.definedBy(route2, sensor2);
9   neg find entrySemaphore(route2, semaphore);

```

```

10
11 route1 != route2;
12 }
13
14 pattern entrySemaphore(route, semaphore)
15 {
16 Route.entry(route, semaphore);
17 }

```

Listing 7: Pattern of the SemaphoreNeighbor query.

```

1 public void transform(final Collection<Object> matches) {
2   for (final Object match : matches) {
3     final SemaphoreNeighborMatch snm = (SemaphoreNeighborMatch) match;
4     snm.getRoute2().setEntry(snm.getSemaphore());
5   }
6 }

```

Listing 8: Transformation of the SemaphoreNeighbor query.

A.1.4 SwitchSensor

```

1 pattern switchSensor(sw)
2 {
3   Switch(sw);
4   neg find hasSensor(sw);
5 }
6
7 pattern hasSensor(sw)
8 {
9   TrackElement.sensor(sw, _);
10 }

```

Listing 9: Pattern of the SwitchSensor query.

```

1 public void transform(final Collection<Object> matches) {
2   for (final Object match : matches) {
3     final SwitchSensorMatch ssm = (SwitchSensorMatch) match;
4     final Sensor sensor = RailwayFactory.eINSTANCE.createSensor();
5     ssm.getSw().setSensor(sensor);
6   }
7 }

```

Listing 10: Transformation of the SwitchSensor query.

A.1.5 SwitchSet

```

1 pattern switchSet(semaphore, route, switchPosition, sw)
2 {
3   Route.entry(route, semaphore);
4   Route.follows(route, switchPosition);
5   SwitchPosition.^switch(switchPosition, sw);
6
7   Semaphore.signal(semaphore, ::GO);
8   SwitchPosition.position(switchPosition, swPP);
9   Switch.currentPosition(sw, swCP);
10
11 swPP != swCP;
12 }

```

Listing 11: Pattern of the SwitchSet query.

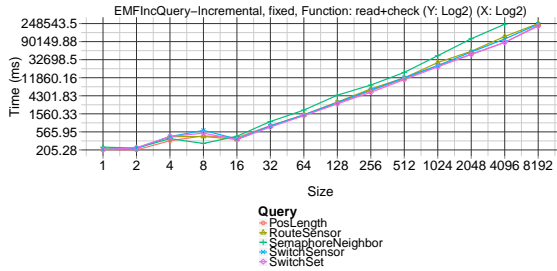
```

1 public void transform(final Collection<Object> matches) {
2     for (final Object match : matches) {
3         final SwitchSetMatch ssm = (SwitchSetMatch) match;
4         ssm.getSw().setCurrentPosition(ssm.getSwitchPosition().getPosition());
5     }
6 }

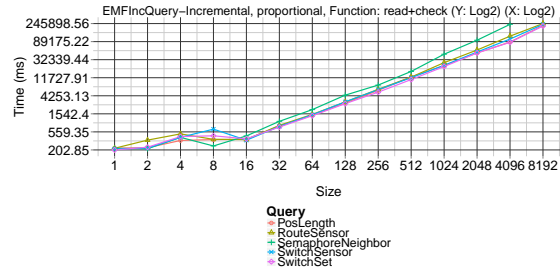
```

Listing 12: Transformation of the SwitchSet query.

A.2 Detailed Benchmark Results

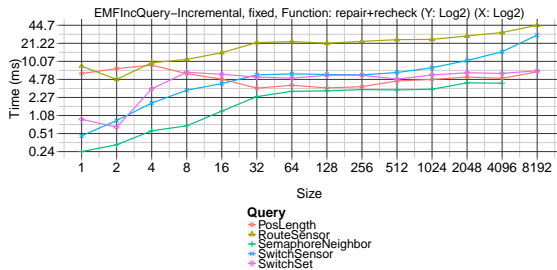


(a) Fixed change set

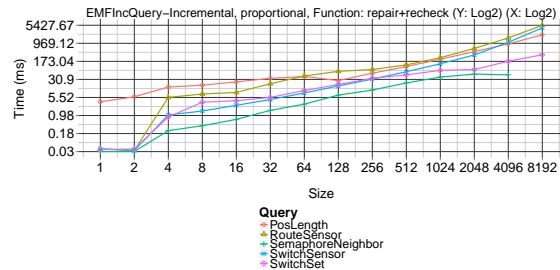


(b) Proportional change set

Figure 7: First validation times for the *incremental* query evaluation strategy.

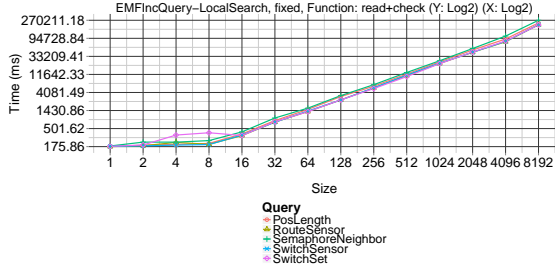


(a) Fixed change set

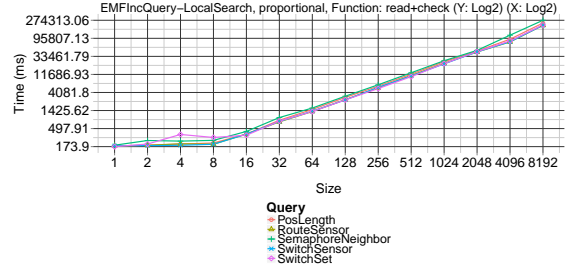


(b) Proportional change set

Figure 8: Revalidation times for the *incremental* query evaluation strategy.

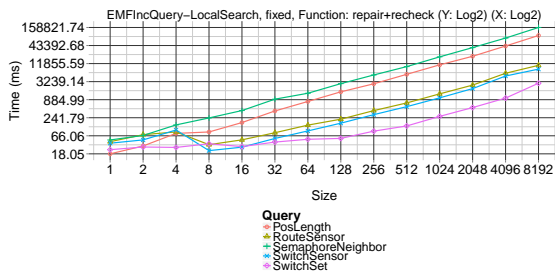


(a) Fixed change set

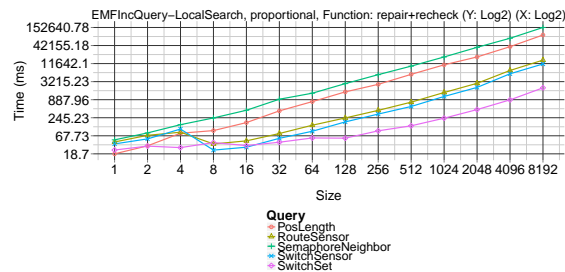


(b) Proportional change set

Figure 9: First validation times for the *local search-based* query evaluation strategy.



(a) Fixed change set



(b) Proportional change set

Figure 10: Revalidation times for the *local search-based* query evaluation strategy.

ChangeSet	Tool	Size	Query	PhaseName	MetricName	MetricValue
fixed	EMFIncQuery-Incremental	1	PosLength	read and check	time	210.298071
fixed	EMFIncQuery-LocalSearch	1	PosLength	read and check	time	178.194132
fixed	EMFIncQuery-Incremental	2	PosLength	read and check	time	205.277574
fixed	EMFIncQuery-LocalSearch	2	PosLength	read and check	time	191.203654
fixed	EMFIncQuery-Incremental	4	PosLength	read and check	time	343.749371
fixed	EMFIncQuery-LocalSearch	4	PosLength	read and check	time	200.046779
fixed	EMFIncQuery-Incremental	8	PosLength	read and check	time	452.233927
fixed	EMFIncQuery-LocalSearch	8	PosLength	read and check	time	212.041935
fixed	EMFIncQuery-Incremental	16	PosLength	read and check	time	410.4975
fixed	EMFIncQuery-LocalSearch	16	PosLength	read and check	time	367.167569
fixed	EMFIncQuery-Incremental	32	PosLength	read and check	time	801.159519
fixed	EMFIncQuery-LocalSearch	32	PosLength	read and check	time	796.58343
fixed	EMFIncQuery-Incremental	64	PosLength	read and check	time	1424.413731
fixed	EMFIncQuery-LocalSearch	64	PosLength	read and check	time	1528.145427
fixed	EMFIncQuery-Incremental	128	PosLength	read and check	time	2826.950307
fixed	EMFIncQuery-LocalSearch	128	PosLength	read and check	time	3219.605669
fixed	EMFIncQuery-Incremental	256	PosLength	read and check	time	5706.533909
fixed	EMFIncQuery-LocalSearch	256	PosLength	read and check	time	5880.109566
fixed	EMFIncQuery-Incremental	512	PosLength	read and check	time	11232.23632
fixed	EMFIncQuery-LocalSearch	512	PosLength	read and check	time	11863.238066
fixed	EMFIncQuery-Incremental	1024	PosLength	read and check	time	22894.174829
fixed	EMFIncQuery-LocalSearch	1024	PosLength	read and check	time	24157.24701
fixed	EMFIncQuery-Incremental	2048	PosLength	read and check	time	44280.148132
fixed	EMFIncQuery-LocalSearch	2048	PosLength	read and check	time	48044.002399
fixed	EMFIncQuery-Incremental	4096	PosLength	read and check	time	86182.94385
fixed	EMFIncQuery-LocalSearch	4096	PosLength	read and check	time	90882.464242
fixed	EMFIncQuery-Incremental	8192	PosLength	read and check	time	225517.528734
fixed	EMFIncQuery-LocalSearch	8192	PosLength	read and check	time	231307.538858
proportional	EMFIncQuery-Incremental	1	PosLength	read and check	time	224.381759
proportional	EMFIncQuery-LocalSearch	1	PosLength	read and check	time	178.372412
proportional	EMFIncQuery-Incremental	2	PosLength	read and check	time	229.628186
proportional	EMFIncQuery-LocalSearch	2	PosLength	read and check	time	188.699673
proportional	EMFIncQuery-Incremental	4	PosLength	read and check	time	344.922543
proportional	EMFIncQuery-LocalSearch	4	PosLength	read and check	time	201.548687
proportional	EMFIncQuery-Incremental	8	PosLength	read and check	time	363.863428
proportional	EMFIncQuery-LocalSearch	8	PosLength	read and check	time	215.223526
proportional	EMFIncQuery-Incremental	16	PosLength	read and check	time	367.06856
proportional	EMFIncQuery-LocalSearch	16	PosLength	read and check	time	360.902505
proportional	EMFIncQuery-Incremental	32	PosLength	read and check	time	776.901558
proportional	EMFIncQuery-LocalSearch	32	PosLength	read and check	time	808.378187
proportional	EMFIncQuery-Incremental	64	PosLength	read and check	time	1426.435449
proportional	EMFIncQuery-LocalSearch	64	PosLength	read and check	time	1519.517305
proportional	EMFIncQuery-Incremental	128	PosLength	read and check	time	2828.249139
proportional	EMFIncQuery-LocalSearch	128	PosLength	read and check	time	3057.928077
proportional	EMFIncQuery-Incremental	256	PosLength	read and check	time	5751.735546
proportional	EMFIncQuery-LocalSearch	256	PosLength	read and check	time	5883.870936
proportional	EMFIncQuery-Incremental	512	PosLength	read and check	time	12236.596997
proportional	EMFIncQuery-LocalSearch	512	PosLength	read and check	time	11843.692537
proportional	EMFIncQuery-Incremental	1024	PosLength	read and check	time	23191.679772
proportional	EMFIncQuery-LocalSearch	1024	PosLength	read and check	time	24560.663609
proportional	EMFIncQuery-Incremental	2048	PosLength	read and check	time	47247.65474
proportional	EMFIncQuery-LocalSearch	2048	PosLength	read and check	time	45466.508926
proportional	EMFIncQuery-Incremental	4096	PosLength	read and check	time	87092.486941
proportional	EMFIncQuery-LocalSearch	4096	PosLength	read and check	time	90897.766231
proportional	EMFIncQuery-Incremental	8192	PosLength	read and check	time	220624.693392
proportional	EMFIncQuery-LocalSearch	8192	PosLength	read and check	time	233514.346171

Table 1: Benchmark results for the PosLength query.

ChangeSet	Tool	Size	Query	PhaseName	MetricName	MetricValue
fixed	EMFIncQuery-Incremental	1	PosLength	modify and revalidate	time	6.103262
fixed	EMFIncQuery-LocalSearch	1	PosLength	modify and revalidate	time	18.049115
fixed	EMFIncQuery-Incremental	2	PosLength	modify and revalidate	time	7.449719
fixed	EMFIncQuery-LocalSearch	2	PosLength	modify and revalidate	time	31.779216
fixed	EMFIncQuery-Incremental	4	PosLength	modify and revalidate	time	8.624596
fixed	EMFIncQuery-LocalSearch	4	PosLength	modify and revalidate	time	78.423165
fixed	EMFIncQuery-Incremental	8	PosLength	modify and revalidate	time	6.058546
fixed	EMFIncQuery-LocalSearch	8	PosLength	modify and revalidate	time	86.905453
fixed	EMFIncQuery-Incremental	16	PosLength	modify and revalidate	time	4.830845
fixed	EMFIncQuery-LocalSearch	16	PosLength	modify and revalidate	time	170.961208
fixed	EMFIncQuery-Incremental	32	PosLength	modify and revalidate	time	3.328704
fixed	EMFIncQuery-LocalSearch	32	PosLength	modify and revalidate	time	393.40069
fixed	EMFIncQuery-Incremental	64	PosLength	modify and revalidate	time	3.763323
fixed	EMFIncQuery-LocalSearch	64	PosLength	modify and revalidate	time	777.62781
fixed	EMFIncQuery-Incremental	128	PosLength	modify and revalidate	time	3.362133
fixed	EMFIncQuery-LocalSearch	128	PosLength	modify and revalidate	time	1555.411909
fixed	EMFIncQuery-Incremental	256	PosLength	modify and revalidate	time	3.540044
fixed	EMFIncQuery-LocalSearch	256	PosLength	modify and revalidate	time	2771.568631
fixed	EMFIncQuery-Incremental	512	PosLength	modify and revalidate	time	4.481992
fixed	EMFIncQuery-LocalSearch	512	PosLength	modify and revalidate	time	5475.972205
fixed	EMFIncQuery-Incremental	1024	PosLength	modify and revalidate	time	4.772878
fixed	EMFIncQuery-LocalSearch	1024	PosLength	modify and revalidate	time	10825.021794
fixed	EMFIncQuery-Incremental	2048	PosLength	modify and revalidate	time	5.279539
fixed	EMFIncQuery-LocalSearch	2048	PosLength	modify and revalidate	time	20035.255302
fixed	EMFIncQuery-Incremental	4096	PosLength	modify and revalidate	time	4.989766
fixed	EMFIncQuery-LocalSearch	4096	PosLength	modify and revalidate	time	41899.598964
fixed	EMFIncQuery-Incremental	8192	PosLength	modify and revalidate	time	6.568381
fixed	EMFIncQuery-LocalSearch	8192	PosLength	modify and revalidate	time	89270.16989
proportional	EMFIncQuery-Incremental	1	PosLength	modify and revalidate	time	3.623648
proportional	EMFIncQuery-LocalSearch	1	PosLength	modify and revalidate	time	18.703936
proportional	EMFIncQuery-Incremental	2	PosLength	modify and revalidate	time	5.890034
proportional	EMFIncQuery-LocalSearch	2	PosLength	modify and revalidate	time	33.095907
proportional	EMFIncQuery-Incremental	4	PosLength	modify and revalidate	time	14.955579
proportional	EMFIncQuery-LocalSearch	4	PosLength	modify and revalidate	time	81.266841
proportional	EMFIncQuery-Incremental	8	PosLength	modify and revalidate	time	17.729648
proportional	EMFIncQuery-LocalSearch	8	PosLength	modify and revalidate	time	98.064957
proportional	EMFIncQuery-Incremental	16	PosLength	modify and revalidate	time	24.467171
proportional	EMFIncQuery-LocalSearch	16	PosLength	modify and revalidate	time	173.529681
proportional	EMFIncQuery-Incremental	32	PosLength	modify and revalidate	time	34.138667
proportional	EMFIncQuery-LocalSearch	32	PosLength	modify and revalidate	time	399.977507
proportional	EMFIncQuery-Incremental	64	PosLength	modify and revalidate	time	40.857772
proportional	EMFIncQuery-LocalSearch	64	PosLength	modify and revalidate	time	773.646625
proportional	EMFIncQuery-Incremental	128	PosLength	modify and revalidate	time	27.551672
proportional	EMFIncQuery-LocalSearch	128	PosLength	modify and revalidate	time	1547.53811
proportional	EMFIncQuery-Incremental	256	PosLength	modify and revalidate	time	55.821364
proportional	EMFIncQuery-LocalSearch	256	PosLength	modify and revalidate	time	2651.152403
proportional	EMFIncQuery-Incremental	512	PosLength	modify and revalidate	time	104.735541
proportional	EMFIncQuery-LocalSearch	512	PosLength	modify and revalidate	time	5401.067104
proportional	EMFIncQuery-Incremental	1024	PosLength	modify and revalidate	time	213.189839
proportional	EMFIncQuery-LocalSearch	1024	PosLength	modify and revalidate	time	10644.245827
proportional	EMFIncQuery-Incremental	2048	PosLength	modify and revalidate	time	437.755818
proportional	EMFIncQuery-LocalSearch	2048	PosLength	modify and revalidate	time	18657.528983
proportional	EMFIncQuery-Incremental	4096	PosLength	modify and revalidate	time	917.094651
proportional	EMFIncQuery-LocalSearch	4096	PosLength	modify and revalidate	time	38830.112617
proportional	EMFIncQuery-Incremental	8192	PosLength	modify and revalidate	time	2172.682751
proportional	EMFIncQuery-LocalSearch	8192	PosLength	modify and revalidate	time	89303.107023

Table 2: Benchmark results for the PosLength query.

ChangeSet	Tool	Size	Query	PhaseName	MetricName	MetricValue
fixed	EMFIncQuery-Incremental	1	RouteSensor	read and check	time	215.721866
fixed	EMFIncQuery-LocalSearch	1	RouteSensor	read and check	time	175.855399
fixed	EMFIncQuery-Incremental	2	RouteSensor	read and check	time	227.193428
fixed	EMFIncQuery-LocalSearch	2	RouteSensor	read and check	time	185.02548
fixed	EMFIncQuery-Incremental	4	RouteSensor	read and check	time	431.596044
fixed	EMFIncQuery-LocalSearch	4	RouteSensor	read and check	time	224.715424
fixed	EMFIncQuery-Incremental	8	RouteSensor	read and check	time	436.545796
fixed	EMFIncQuery-LocalSearch	8	RouteSensor	read and check	time	201.046293
fixed	EMFIncQuery-Incremental	16	RouteSensor	read and check	time	371.533001
fixed	EMFIncQuery-LocalSearch	16	RouteSensor	read and check	time	333.507682
fixed	EMFIncQuery-Incremental	32	RouteSensor	read and check	time	789.506427
fixed	EMFIncQuery-LocalSearch	32	RouteSensor	read and check	time	731.736499
fixed	EMFIncQuery-Incremental	64	RouteSensor	read and check	time	1485.73648
fixed	EMFIncQuery-LocalSearch	64	RouteSensor	read and check	time	1345.977827
fixed	EMFIncQuery-Incremental	128	RouteSensor	read and check	time	3014.091669
fixed	EMFIncQuery-LocalSearch	128	RouteSensor	read and check	time	2649.252062
fixed	EMFIncQuery-Incremental	256	RouteSensor	read and check	time	6338.0945
fixed	EMFIncQuery-LocalSearch	256	RouteSensor	read and check	time	5292.011608
fixed	EMFIncQuery-Incremental	512	RouteSensor	read and check	time	11728.671796
fixed	EMFIncQuery-LocalSearch	512	RouteSensor	read and check	time	10901.159666
fixed	EMFIncQuery-Incremental	1024	RouteSensor	read and check	time	27821.992056
fixed	EMFIncQuery-LocalSearch	1024	RouteSensor	read and check	time	21982.096913
fixed	EMFIncQuery-Incremental	2048	RouteSensor	read and check	time	52397.700303
fixed	EMFIncQuery-LocalSearch	2048	RouteSensor	read and check	time	42075.807487
fixed	EMFIncQuery-Incremental	4096	RouteSensor	read and check	time	120394.147537
fixed	EMFIncQuery-LocalSearch	4096	RouteSensor	read and check	time	77697.378225
fixed	EMFIncQuery-Incremental	8192	RouteSensor	read and check	time	248543.496509
fixed	EMFIncQuery-LocalSearch	8192	RouteSensor	read and check	time	207841.733247
proportional	EMFIncQuery-Incremental	1	RouteSensor	read and check	time	222.867966
proportional	EMFIncQuery-LocalSearch	1	RouteSensor	read and check	time	182.249332
proportional	EMFIncQuery-Incremental	2	RouteSensor	read and check	time	351.933322
proportional	EMFIncQuery-LocalSearch	2	RouteSensor	read and check	time	188.291042
proportional	EMFIncQuery-Incremental	4	RouteSensor	read and check	time	499.211892
proportional	EMFIncQuery-LocalSearch	4	RouteSensor	read and check	time	205.069178
proportional	EMFIncQuery-Incremental	8	RouteSensor	read and check	time	367.802443
proportional	EMFIncQuery-LocalSearch	8	RouteSensor	read and check	time	200.554519
proportional	EMFIncQuery-Incremental	16	RouteSensor	read and check	time	362.626905
proportional	EMFIncQuery-LocalSearch	16	RouteSensor	read and check	time	361.76396
proportional	EMFIncQuery-Incremental	32	RouteSensor	read and check	time	806.491356
proportional	EMFIncQuery-LocalSearch	32	RouteSensor	read and check	time	735.633516
proportional	EMFIncQuery-Incremental	64	RouteSensor	read and check	time	1493.348463
proportional	EMFIncQuery-LocalSearch	64	RouteSensor	read and check	time	1348.179156
proportional	EMFIncQuery-Incremental	128	RouteSensor	read and check	time	3000.006355
proportional	EMFIncQuery-LocalSearch	128	RouteSensor	read and check	time	2689.06461
proportional	EMFIncQuery-Incremental	256	RouteSensor	read and check	time	6123.016756
proportional	EMFIncQuery-LocalSearch	256	RouteSensor	read and check	time	5361.599056
proportional	EMFIncQuery-Incremental	512	RouteSensor	read and check	time	12149.338585
proportional	EMFIncQuery-LocalSearch	512	RouteSensor	read and check	time	10928.122561
proportional	EMFIncQuery-Incremental	1024	RouteSensor	read and check	time	27387.193941
proportional	EMFIncQuery-LocalSearch	1024	RouteSensor	read and check	time	22263.203791
proportional	EMFIncQuery-Incremental	2048	RouteSensor	read and check	time	55600.828061
proportional	EMFIncQuery-LocalSearch	2048	RouteSensor	read and check	time	43194.689168
proportional	EMFIncQuery-Incremental	4096	RouteSensor	read and check	time	121172.728516
proportional	EMFIncQuery-LocalSearch	4096	RouteSensor	read and check	time	77690.516919
proportional	EMFIncQuery-Incremental	8192	RouteSensor	read and check	time	245898.560203
proportional	EMFIncQuery-LocalSearch	8192	RouteSensor	read and check	time	204455.993189

Table 3: Benchmark results for the RouteSensor query.

ChangeSet	Tool	Size	Query	PhaseName	MetricName	MetricValue
fixed	EMFIncQuery-Incremental	1	RouteSensor	modify and revalidate	time	8.260157
fixed	EMFIncQuery-LocalSearch	1	RouteSensor	modify and revalidate	time	43.253546
fixed	EMFIncQuery-Incremental	2	RouteSensor	modify and revalidate	time	4.793492
fixed	EMFIncQuery-LocalSearch	2	RouteSensor	modify and revalidate	time	71.546014
fixed	EMFIncQuery-Incremental	4	RouteSensor	modify and revalidate	time	9.520789
fixed	EMFIncQuery-LocalSearch	4	RouteSensor	modify and revalidate	time	87.314068
fixed	EMFIncQuery-Incremental	8	RouteSensor	modify and revalidate	time	10.894073
fixed	EMFIncQuery-LocalSearch	8	RouteSensor	modify and revalidate	time	34.837744
fixed	EMFIncQuery-Incremental	16	RouteSensor	modify and revalidate	time	14.441809
fixed	EMFIncQuery-LocalSearch	16	RouteSensor	modify and revalidate	time	49.340817
fixed	EMFIncQuery-Incremental	32	RouteSensor	modify and revalidate	time	21.849251
fixed	EMFIncQuery-LocalSearch	32	RouteSensor	modify and revalidate	time	82.257334
fixed	EMFIncQuery-Incremental	64	RouteSensor	modify and revalidate	time	22.774575
fixed	EMFIncQuery-LocalSearch	64	RouteSensor	modify and revalidate	time	142.119137
fixed	EMFIncQuery-Incremental	128	RouteSensor	modify and revalidate	time	21.31011
fixed	EMFIncQuery-LocalSearch	128	RouteSensor	modify and revalidate	time	217.700792
fixed	EMFIncQuery-Incremental	256	RouteSensor	modify and revalidate	time	22.960783
fixed	EMFIncQuery-LocalSearch	256	RouteSensor	modify and revalidate	time	403.424013
fixed	EMFIncQuery-Incremental	512	RouteSensor	modify and revalidate	time	24.649783
fixed	EMFIncQuery-LocalSearch	512	RouteSensor	modify and revalidate	time	700.821656
fixed	EMFIncQuery-Incremental	1024	RouteSensor	modify and revalidate	time	24.943514
fixed	EMFIncQuery-LocalSearch	1024	RouteSensor	modify and revalidate	time	1344.97208
fixed	EMFIncQuery-Incremental	2048	RouteSensor	modify and revalidate	time	28.683686
fixed	EMFIncQuery-LocalSearch	2048	RouteSensor	modify and revalidate	time	2524.912137
fixed	EMFIncQuery-Incremental	4096	RouteSensor	modify and revalidate	time	33.167976
fixed	EMFIncQuery-LocalSearch	4096	RouteSensor	modify and revalidate	time	5911.011832
fixed	EMFIncQuery-Incremental	8192	RouteSensor	modify and revalidate	time	44.697337
fixed	EMFIncQuery-LocalSearch	8192	RouteSensor	modify and revalidate	time	10458.141634
proportional	EMFIncQuery-Incremental	1	RouteSensor	modify and revalidate	time	0.040294
proportional	EMFIncQuery-LocalSearch	1	RouteSensor	modify and revalidate	time	43.602038
proportional	EMFIncQuery-Incremental	2	RouteSensor	modify and revalidate	time	0.035133
proportional	EMFIncQuery-LocalSearch	2	RouteSensor	modify and revalidate	time	69.979906
proportional	EMFIncQuery-Incremental	4	RouteSensor	modify and revalidate	time	5.560636
proportional	EMFIncQuery-LocalSearch	4	RouteSensor	modify and revalidate	time	87.452915
proportional	EMFIncQuery-Incremental	8	RouteSensor	modify and revalidate	time	7.666914
proportional	EMFIncQuery-LocalSearch	8	RouteSensor	modify and revalidate	time	37.851678
proportional	EMFIncQuery-Incremental	16	RouteSensor	modify and revalidate	time	8.908098
proportional	EMFIncQuery-LocalSearch	16	RouteSensor	modify and revalidate	time	47.113066
proportional	EMFIncQuery-Incremental	32	RouteSensor	modify and revalidate	time	20.372224
proportional	EMFIncQuery-LocalSearch	32	RouteSensor	modify and revalidate	time	79.665794
proportional	EMFIncQuery-Incremental	64	RouteSensor	modify and revalidate	time	42.722508
proportional	EMFIncQuery-LocalSearch	64	RouteSensor	modify and revalidate	time	143.841329
proportional	EMFIncQuery-Incremental	128	RouteSensor	modify and revalidate	time	66.745304
proportional	EMFIncQuery-LocalSearch	128	RouteSensor	modify and revalidate	time	241.419406
proportional	EMFIncQuery-Incremental	256	RouteSensor	modify and revalidate	time	79.390471
proportional	EMFIncQuery-LocalSearch	256	RouteSensor	modify and revalidate	time	414.688406
proportional	EMFIncQuery-Incremental	512	RouteSensor	modify and revalidate	time	123.654424
proportional	EMFIncQuery-LocalSearch	512	RouteSensor	modify and revalidate	time	744.099881
proportional	EMFIncQuery-Incremental	1024	RouteSensor	modify and revalidate	time	245.683569
proportional	EMFIncQuery-LocalSearch	1024	RouteSensor	modify and revalidate	time	1481.35725
proportional	EMFIncQuery-Incremental	2048	RouteSensor	modify and revalidate	time	593.285299
proportional	EMFIncQuery-LocalSearch	2048	RouteSensor	modify and revalidate	time	2854.712723
proportional	EMFIncQuery-Incremental	4096	RouteSensor	modify and revalidate	time	1614.758103
proportional	EMFIncQuery-LocalSearch	4096	RouteSensor	modify and revalidate	time	7125.842407
proportional	EMFIncQuery-Incremental	8192	RouteSensor	modify and revalidate	time	5427.66646
proportional	EMFIncQuery-LocalSearch	8192	RouteSensor	modify and revalidate	time	14897.012763

Table 4: Benchmark results for the RouteSensor query.

ChangeSet	Tool	Size	Query	PhaseName	MetricName	MetricValue
fixed	EMFIncQuery-Incremental	1	SemaphoreNeighbor	read and check	time	240.232289
fixed	EMFIncQuery-LocalSearch	1	SemaphoreNeighbor	read and check	time	182.510278
fixed	EMFIncQuery-Incremental	2	SemaphoreNeighbor	read and check	time	227.46587
fixed	EMFIncQuery-LocalSearch	2	SemaphoreNeighbor	read and check	time	228.41688
fixed	EMFIncQuery-Incremental	4	SemaphoreNeighbor	read and check	time	386.769898
fixed	EMFIncQuery-LocalSearch	4	SemaphoreNeighbor	read and check	time	228.362674
fixed	EMFIncQuery-Incremental	8	SemaphoreNeighbor	read and check	time	295.670713
fixed	EMFIncQuery-LocalSearch	8	SemaphoreNeighbor	read and check	time	249.644801
fixed	EMFIncQuery-Incremental	16	SemaphoreNeighbor	read and check	time	442.122157
fixed	EMFIncQuery-LocalSearch	16	SemaphoreNeighbor	read and check	time	413.637163
fixed	EMFIncQuery-Incremental	32	SemaphoreNeighbor	read and check	time	1013.83655
fixed	EMFIncQuery-LocalSearch	32	SemaphoreNeighbor	read and check	time	927.578515
fixed	EMFIncQuery-Incremental	64	SemaphoreNeighbor	read and check	time	1925.260776
fixed	EMFIncQuery-LocalSearch	64	SemaphoreNeighbor	read and check	time	1643.771442
fixed	EMFIncQuery-Incremental	128	SemaphoreNeighbor	read and check	time	4446.306889
fixed	EMFIncQuery-LocalSearch	128	SemaphoreNeighbor	read and check	time	3400.386332
fixed	EMFIncQuery-Incremental	256	SemaphoreNeighbor	read and check	time	7856.981111
fixed	EMFIncQuery-LocalSearch	256	SemaphoreNeighbor	read and check	time	6416.952077
fixed	EMFIncQuery-Incremental	512	SemaphoreNeighbor	read and check	time	15988.99645
fixed	EMFIncQuery-LocalSearch	512	SemaphoreNeighbor	read and check	time	13022.04044
fixed	EMFIncQuery-Incremental	1024	SemaphoreNeighbor	read and check	time	40866.085543
fixed	EMFIncQuery-LocalSearch	1024	SemaphoreNeighbor	read and check	time	25767.134546
fixed	EMFIncQuery-Incremental	2048	SemaphoreNeighbor	read and check	time	105934.257489
fixed	EMFIncQuery-LocalSearch	2048	SemaphoreNeighbor	read and check	time	52355.644842
fixed	EMFIncQuery-Incremental	4096	SemaphoreNeighbor	read and check	time	239544.128485
fixed	EMFIncQuery-LocalSearch	4096	SemaphoreNeighbor	read and check	time	107863.641072
fixed	EMFIncQuery-LocalSearch	8192	SemaphoreNeighbor	read and check	time	270211.180376
proportional	EMFIncQuery-Incremental	1	SemaphoreNeighbor	read and check	time	221.744701
proportional	EMFIncQuery-LocalSearch	1	SemaphoreNeighbor	read and check	time	189.005514
proportional	EMFIncQuery-Incremental	2	SemaphoreNeighbor	read and check	time	216.958704
proportional	EMFIncQuery-LocalSearch	2	SemaphoreNeighbor	read and check	time	248.456908
proportional	EMFIncQuery-Incremental	4	SemaphoreNeighbor	read and check	time	411.017049
proportional	EMFIncQuery-LocalSearch	4	SemaphoreNeighbor	read and check	time	239.809039
proportional	EMFIncQuery-Incremental	8	SemaphoreNeighbor	read and check	time	253.538057
proportional	EMFIncQuery-LocalSearch	8	SemaphoreNeighbor	read and check	time	250.455944
proportional	EMFIncQuery-Incremental	16	SemaphoreNeighbor	read and check	time	445.688801
proportional	EMFIncQuery-LocalSearch	16	SemaphoreNeighbor	read and check	time	421.666751
proportional	EMFIncQuery-Incremental	32	SemaphoreNeighbor	read and check	time	1011.620549
proportional	EMFIncQuery-LocalSearch	32	SemaphoreNeighbor	read and check	time	947.223181
proportional	EMFIncQuery-Incremental	64	SemaphoreNeighbor	read and check	time	1955.677607
proportional	EMFIncQuery-LocalSearch	64	SemaphoreNeighbor	read and check	time	1649.115153
proportional	EMFIncQuery-Incremental	128	SemaphoreNeighbor	read and check	time	4406.712057
proportional	EMFIncQuery-LocalSearch	128	SemaphoreNeighbor	read and check	time	3281.632197
proportional	EMFIncQuery-Incremental	256	SemaphoreNeighbor	read and check	time	7763.485768
proportional	EMFIncQuery-LocalSearch	256	SemaphoreNeighbor	read and check	time	6390.738409
proportional	EMFIncQuery-Incremental	512	SemaphoreNeighbor	read and check	time	16694.718066
proportional	EMFIncQuery-LocalSearch	512	SemaphoreNeighbor	read and check	time	12879.359014
proportional	EMFIncQuery-Incremental	1024	SemaphoreNeighbor	read and check	time	43986.695158
proportional	EMFIncQuery-LocalSearch	1024	SemaphoreNeighbor	read and check	time	25950.281272
proportional	EMFIncQuery-Incremental	2048	SemaphoreNeighbor	read and check	time	96630.698725
proportional	EMFIncQuery-LocalSearch	2048	SemaphoreNeighbor	read and check	time	47487.288389
proportional	EMFIncQuery-Incremental	4096	SemaphoreNeighbor	read and check	time	235246.297145
proportional	EMFIncQuery-LocalSearch	4096	SemaphoreNeighbor	read and check	time	114993.525253
proportional	EMFIncQuery-LocalSearch	8192	SemaphoreNeighbor	read and check	time	274313.055853

Table 5: Benchmark results for the SemaphoreNeighbor query.

ChangeSet	Tool	Size	Query	PhaseName	MetricName	MetricValue
fixed	EMFIncQuery-Incremental	1	SemaphoreNeighbor	modify and revalidate	time	0.242763
fixed	EMFIncQuery-LocalSearch	1	SemaphoreNeighbor	modify and revalidate	time	48.919823
fixed	EMFIncQuery-Incremental	2	SemaphoreNeighbor	modify and revalidate	time	0.322082
fixed	EMFIncQuery-LocalSearch	2	SemaphoreNeighbor	modify and revalidate	time	67.607963
fixed	EMFIncQuery-Incremental	4	SemaphoreNeighbor	modify and revalidate	time	0.573263
fixed	EMFIncQuery-LocalSearch	4	SemaphoreNeighbor	modify and revalidate	time	144.420809
fixed	EMFIncQuery-Incremental	8	SemaphoreNeighbor	modify and revalidate	time	0.703411
fixed	EMFIncQuery-LocalSearch	8	SemaphoreNeighbor	modify and revalidate	time	238.202911
fixed	EMFIncQuery-Incremental	16	SemaphoreNeighbor	modify and revalidate	time	1.291134
fixed	EMFIncQuery-LocalSearch	16	SemaphoreNeighbor	modify and revalidate	time	405.1162
fixed	EMFIncQuery-Incremental	32	SemaphoreNeighbor	modify and revalidate	time	2.348602
fixed	EMFIncQuery-LocalSearch	32	SemaphoreNeighbor	modify and revalidate	time	917.987957
fixed	EMFIncQuery-Incremental	64	SemaphoreNeighbor	modify and revalidate	time	2.924311
fixed	EMFIncQuery-LocalSearch	64	SemaphoreNeighbor	modify and revalidate	time	1404.849753
fixed	EMFIncQuery-Incremental	128	SemaphoreNeighbor	modify and revalidate	time	2.979185
fixed	EMFIncQuery-LocalSearch	128	SemaphoreNeighbor	modify and revalidate	time	2803.220991
fixed	EMFIncQuery-Incremental	256	SemaphoreNeighbor	modify and revalidate	time	3.140119
fixed	EMFIncQuery-LocalSearch	256	SemaphoreNeighbor	modify and revalidate	time	5228.621765
fixed	EMFIncQuery-Incremental	512	SemaphoreNeighbor	modify and revalidate	time	3.100527
fixed	EMFIncQuery-LocalSearch	512	SemaphoreNeighbor	modify and revalidate	time	9532.445944
fixed	EMFIncQuery-Incremental	1024	SemaphoreNeighbor	modify and revalidate	time	3.184848
fixed	EMFIncQuery-LocalSearch	1024	SemaphoreNeighbor	modify and revalidate	time	19221.01202
fixed	EMFIncQuery-Incremental	2048	SemaphoreNeighbor	modify and revalidate	time	4.14882
fixed	EMFIncQuery-LocalSearch	2048	SemaphoreNeighbor	modify and revalidate	time	37380.322156
fixed	EMFIncQuery-Incremental	4096	SemaphoreNeighbor	modify and revalidate	time	4.092549
fixed	EMFIncQuery-LocalSearch	4096	SemaphoreNeighbor	modify and revalidate	time	74139.19707
fixed	EMFIncQuery-LocalSearch	8192	SemaphoreNeighbor	modify and revalidate	time	158821.741816
proportional	EMFIncQuery-Incremental	1	SemaphoreNeighbor	modify and revalidate	time	0.031402
proportional	EMFIncQuery-LocalSearch	1	SemaphoreNeighbor	modify and revalidate	time	50.690984
proportional	EMFIncQuery-Incremental	2	SemaphoreNeighbor	modify and revalidate	time	0.031876
proportional	EMFIncQuery-LocalSearch	2	SemaphoreNeighbor	modify and revalidate	time	83.068755
proportional	EMFIncQuery-Incremental	4	SemaphoreNeighbor	modify and revalidate	time	0.232779
proportional	EMFIncQuery-LocalSearch	4	SemaphoreNeighbor	modify and revalidate	time	149.420429
proportional	EMFIncQuery-Incremental	8	SemaphoreNeighbor	modify and revalidate	time	0.370724
proportional	EMFIncQuery-LocalSearch	8	SemaphoreNeighbor	modify and revalidate	time	241.393745
proportional	EMFIncQuery-Incremental	16	SemaphoreNeighbor	modify and revalidate	time	0.679953
proportional	EMFIncQuery-LocalSearch	16	SemaphoreNeighbor	modify and revalidate	time	417.64153
proportional	EMFIncQuery-Incremental	32	SemaphoreNeighbor	modify and revalidate	time	1.608991
proportional	EMFIncQuery-LocalSearch	32	SemaphoreNeighbor	modify and revalidate	time	917.727451
proportional	EMFIncQuery-Incremental	64	SemaphoreNeighbor	modify and revalidate	time	2.914975
proportional	EMFIncQuery-LocalSearch	64	SemaphoreNeighbor	modify and revalidate	time	1409.064017
proportional	EMFIncQuery-Incremental	128	SemaphoreNeighbor	modify and revalidate	time	6.909493
proportional	EMFIncQuery-LocalSearch	128	SemaphoreNeighbor	modify and revalidate	time	2788.790444
proportional	EMFIncQuery-Incremental	256	SemaphoreNeighbor	modify and revalidate	time	11.186405
proportional	EMFIncQuery-LocalSearch	256	SemaphoreNeighbor	modify and revalidate	time	5286.273787
proportional	EMFIncQuery-Incremental	512	SemaphoreNeighbor	modify and revalidate	time	21.959866
proportional	EMFIncQuery-LocalSearch	512	SemaphoreNeighbor	modify and revalidate	time	9707.476773
proportional	EMFIncQuery-Incremental	1024	SemaphoreNeighbor	modify and revalidate	time	38.594706
proportional	EMFIncQuery-LocalSearch	1024	SemaphoreNeighbor	modify and revalidate	time	18654.979515
proportional	EMFIncQuery-Incremental	2048	SemaphoreNeighbor	modify and revalidate	time	51.27372
proportional	EMFIncQuery-LocalSearch	2048	SemaphoreNeighbor	modify and revalidate	time	37016.909862
proportional	EMFIncQuery-Incremental	4096	SemaphoreNeighbor	modify and revalidate	time	47.797887
proportional	EMFIncQuery-LocalSearch	4096	SemaphoreNeighbor	modify and revalidate	time	70728.913349
proportional	EMFIncQuery-LocalSearch	8192	SemaphoreNeighbor	modify and revalidate	time	152640.781343

Table 6: Benchmark results for the SemaphoreNeighbor query.

ChangeSet	Tool	Size	Query	PhaseName	MetricName	MetricValue
fixed	EMFIncQuery-Incremental	1	SwitchSensor	read and check	time	212.145195
fixed	EMFIncQuery-LocalSearch	1	SwitchSensor	read and check	time	178.862836
fixed	EMFIncQuery-Incremental	2	SwitchSensor	read and check	time	224.406038
fixed	EMFIncQuery-LocalSearch	2	SwitchSensor	read and check	time	183.698027
fixed	EMFIncQuery-Incremental	4	SwitchSensor	read and check	time	433.539712
fixed	EMFIncQuery-LocalSearch	4	SwitchSensor	read and check	time	192.319116
fixed	EMFIncQuery-Incremental	8	SwitchSensor	read and check	time	616.233763
fixed	EMFIncQuery-LocalSearch	8	SwitchSensor	read and check	time	198.133643
fixed	EMFIncQuery-Incremental	16	SwitchSensor	read and check	time	378.528485
fixed	EMFIncQuery-LocalSearch	16	SwitchSensor	read and check	time	344.531458
fixed	EMFIncQuery-Incremental	32	SwitchSensor	read and check	time	786.93385
fixed	EMFIncQuery-LocalSearch	32	SwitchSensor	read and check	time	726.809429
fixed	EMFIncQuery-Incremental	64	SwitchSensor	read and check	time	1466.608066
fixed	EMFIncQuery-LocalSearch	64	SwitchSensor	read and check	time	1388.318983
fixed	EMFIncQuery-Incremental	128	SwitchSensor	read and check	time	2947.953852
fixed	EMFIncQuery-LocalSearch	128	SwitchSensor	read and check	time	2642.372399
fixed	EMFIncQuery-Incremental	256	SwitchSensor	read and check	time	5960.293711
fixed	EMFIncQuery-LocalSearch	256	SwitchSensor	read and check	time	5347.390309
fixed	EMFIncQuery-Incremental	512	SwitchSensor	read and check	time	11861.257029
fixed	EMFIncQuery-LocalSearch	512	SwitchSensor	read and check	time	11146.535654
fixed	EMFIncQuery-Incremental	1024	SwitchSensor	read and check	time	23584.506626
fixed	EMFIncQuery-LocalSearch	1024	SwitchSensor	read and check	time	22417.285269
fixed	EMFIncQuery-Incremental	2048	SwitchSensor	read and check	time	50169.889401
fixed	EMFIncQuery-LocalSearch	2048	SwitchSensor	read and check	time	42232.241293
fixed	EMFIncQuery-Incremental	4096	SwitchSensor	read and check	time	104605.912821
fixed	EMFIncQuery-LocalSearch	4096	SwitchSensor	read and check	time	79086.409073
fixed	EMFIncQuery-Incremental	8192	SwitchSensor	read and check	time	240151.226551
fixed	EMFIncQuery-LocalSearch	8192	SwitchSensor	read and check	time	209477.978433
proportional	EMFIncQuery-Incremental	1	SwitchSensor	read and check	time	213.801446
proportional	EMFIncQuery-LocalSearch	1	SwitchSensor	read and check	time	182.981747
proportional	EMFIncQuery-Incremental	2	SwitchSensor	read and check	time	225.278142
proportional	EMFIncQuery-LocalSearch	2	SwitchSensor	read and check	time	184.517582
proportional	EMFIncQuery-Incremental	4	SwitchSensor	read and check	time	411.685587
proportional	EMFIncQuery-LocalSearch	4	SwitchSensor	read and check	time	188.30868
proportional	EMFIncQuery-Incremental	8	SwitchSensor	read and check	time	652.210057
proportional	EMFIncQuery-LocalSearch	8	SwitchSensor	read and check	time	199.358978
proportional	EMFIncQuery-Incremental	16	SwitchSensor	read and check	time	350.374714
proportional	EMFIncQuery-LocalSearch	16	SwitchSensor	read and check	time	361.286201
proportional	EMFIncQuery-Incremental	32	SwitchSensor	read and check	time	761.357659
proportional	EMFIncQuery-LocalSearch	32	SwitchSensor	read and check	time	752.746563
proportional	EMFIncQuery-Incremental	64	SwitchSensor	read and check	time	1462.276392
proportional	EMFIncQuery-LocalSearch	64	SwitchSensor	read and check	time	1370.598727
proportional	EMFIncQuery-Incremental	128	SwitchSensor	read and check	time	3027.1606
proportional	EMFIncQuery-LocalSearch	128	SwitchSensor	read and check	time	2650.008175
proportional	EMFIncQuery-Incremental	256	SwitchSensor	read and check	time	6005.510775
proportional	EMFIncQuery-LocalSearch	256	SwitchSensor	read and check	time	5492.543772
proportional	EMFIncQuery-Incremental	512	SwitchSensor	read and check	time	11762.286475
proportional	EMFIncQuery-LocalSearch	512	SwitchSensor	read and check	time	10692.195111
proportional	EMFIncQuery-Incremental	1024	SwitchSensor	read and check	time	23570.287008
proportional	EMFIncQuery-LocalSearch	1024	SwitchSensor	read and check	time	21643.955781
proportional	EMFIncQuery-Incremental	2048	SwitchSensor	read and check	time	49683.130107
proportional	EMFIncQuery-LocalSearch	2048	SwitchSensor	read and check	time	43369.487551
proportional	EMFIncQuery-Incremental	4096	SwitchSensor	read and check	time	102994.540092
proportional	EMFIncQuery-LocalSearch	4096	SwitchSensor	read and check	time	78256.129946
proportional	EMFIncQuery-Incremental	8192	SwitchSensor	read and check	time	234484.572557
proportional	EMFIncQuery-LocalSearch	8192	SwitchSensor	read and check	time	204665.946322

Table 7: Benchmark results for the SwitchSensor query.

ChangeSet	Tool	Size	Query	PhaseName	MetricName	MetricValue
fixed	EMFIncQuery-Incremental	1	SwitchSensor	modify and revalidate	time	0.465696
fixed	EMFIncQuery-LocalSearch	1	SwitchSensor	modify and revalidate	time	38.761292
fixed	EMFIncQuery-Incremental	2	SwitchSensor	modify and revalidate	time	0.876356
fixed	EMFIncQuery-LocalSearch	2	SwitchSensor	modify and revalidate	time	49.098053
fixed	EMFIncQuery-Incremental	4	SwitchSensor	modify and revalidate	time	1.800714
fixed	EMFIncQuery-LocalSearch	4	SwitchSensor	modify and revalidate	time	100.187725
fixed	EMFIncQuery-Incremental	8	SwitchSensor	modify and revalidate	time	3.061915
fixed	EMFIncQuery-LocalSearch	8	SwitchSensor	modify and revalidate	time	22.73719
fixed	EMFIncQuery-Incremental	16	SwitchSensor	modify and revalidate	time	4.022412
fixed	EMFIncQuery-LocalSearch	16	SwitchSensor	modify and revalidate	time	29.137434
fixed	EMFIncQuery-Incremental	32	SwitchSensor	modify and revalidate	time	5.755359
fixed	EMFIncQuery-LocalSearch	32	SwitchSensor	modify and revalidate	time	54.47707
fixed	EMFIncQuery-Incremental	64	SwitchSensor	modify and revalidate	time	6.014394
fixed	EMFIncQuery-LocalSearch	64	SwitchSensor	modify and revalidate	time	93.700505
fixed	EMFIncQuery-Incremental	128	SwitchSensor	modify and revalidate	time	5.864815
fixed	EMFIncQuery-LocalSearch	128	SwitchSensor	modify and revalidate	time	163.466406
fixed	EMFIncQuery-Incremental	256	SwitchSensor	modify and revalidate	time	5.760812
fixed	EMFIncQuery-LocalSearch	256	SwitchSensor	modify and revalidate	time	301.866686
fixed	EMFIncQuery-Incremental	512	SwitchSensor	modify and revalidate	time	6.344689
fixed	EMFIncQuery-LocalSearch	512	SwitchSensor	modify and revalidate	time	536.210619
fixed	EMFIncQuery-Incremental	1024	SwitchSensor	modify and revalidate	time	7.754294
fixed	EMFIncQuery-LocalSearch	1024	SwitchSensor	modify and revalidate	time	1010.215018
fixed	EMFIncQuery-Incremental	2048	SwitchSensor	modify and revalidate	time	10.409721
fixed	EMFIncQuery-LocalSearch	2048	SwitchSensor	modify and revalidate	time	1961.527318
fixed	EMFIncQuery-Incremental	4096	SwitchSensor	modify and revalidate	time	14.983758
fixed	EMFIncQuery-LocalSearch	4096	SwitchSensor	modify and revalidate	time	4850.828713
fixed	EMFIncQuery-Incremental	8192	SwitchSensor	modify and revalidate	time	29.774253
fixed	EMFIncQuery-LocalSearch	8192	SwitchSensor	modify and revalidate	time	7956.81605
proportional	EMFIncQuery-Incremental	1	SwitchSensor	modify and revalidate	time	0.04129
proportional	EMFIncQuery-LocalSearch	1	SwitchSensor	modify and revalidate	time	37.971389
proportional	EMFIncQuery-Incremental	2	SwitchSensor	modify and revalidate	time	0.034927
proportional	EMFIncQuery-LocalSearch	2	SwitchSensor	modify and revalidate	time	54.251865
proportional	EMFIncQuery-Incremental	4	SwitchSensor	modify and revalidate	time	1.040301
proportional	EMFIncQuery-LocalSearch	4	SwitchSensor	modify and revalidate	time	109.519572
proportional	EMFIncQuery-Incremental	8	SwitchSensor	modify and revalidate	time	1.509935
proportional	EMFIncQuery-LocalSearch	8	SwitchSensor	modify and revalidate	time	24.404587
proportional	EMFIncQuery-Incremental	16	SwitchSensor	modify and revalidate	time	2.602653
proportional	EMFIncQuery-LocalSearch	16	SwitchSensor	modify and revalidate	time	30.023173
proportional	EMFIncQuery-Incremental	32	SwitchSensor	modify and revalidate	time	4.529747
proportional	EMFIncQuery-LocalSearch	32	SwitchSensor	modify and revalidate	time	56.497694
proportional	EMFIncQuery-Incremental	64	SwitchSensor	modify and revalidate	time	8.45335
proportional	EMFIncQuery-LocalSearch	64	SwitchSensor	modify and revalidate	time	93.539656
proportional	EMFIncQuery-Incremental	128	SwitchSensor	modify and revalidate	time	16.496139
proportional	EMFIncQuery-LocalSearch	128	SwitchSensor	modify and revalidate	time	182.149298
proportional	EMFIncQuery-Incremental	256	SwitchSensor	modify and revalidate	time	31.732373
proportional	EMFIncQuery-LocalSearch	256	SwitchSensor	modify and revalidate	time	318.135602
proportional	EMFIncQuery-Incremental	512	SwitchSensor	modify and revalidate	time	64.42754
proportional	EMFIncQuery-LocalSearch	512	SwitchSensor	modify and revalidate	time	547.279917
proportional	EMFIncQuery-Incremental	1024	SwitchSensor	modify and revalidate	time	136.801998
proportional	EMFIncQuery-LocalSearch	1024	SwitchSensor	modify and revalidate	time	1117.288917
proportional	EMFIncQuery-Incremental	2048	SwitchSensor	modify and revalidate	time	317.503777
proportional	EMFIncQuery-LocalSearch	2048	SwitchSensor	modify and revalidate	time	2128.361921
proportional	EMFIncQuery-Incremental	4096	SwitchSensor	modify and revalidate	time	1067.108193
proportional	EMFIncQuery-LocalSearch	4096	SwitchSensor	modify and revalidate	time	5626.040347
proportional	EMFIncQuery-Incremental	8192	SwitchSensor	modify and revalidate	time	4231.575623
proportional	EMFIncQuery-LocalSearch	8192	SwitchSensor	modify and revalidate	time	11322.67485

Table 8: Benchmark results for the SwitchSensor query.

ChangeSet	Tool	Size	Query	PhaseName	MetricName	MetricValue
fixed	EMFIncQuery-Incremental	1	SwitchSet	read and check	time	208.286552
fixed	EMFIncQuery-LocalSearch	1	SwitchSet	read and check	time	178.641895
fixed	EMFIncQuery-Incremental	2	SwitchSet	read and check	time	232.598123
fixed	EMFIncQuery-LocalSearch	2	SwitchSet	read and check	time	193.606064
fixed	EMFIncQuery-Incremental	4	SwitchSet	read and check	time	435.633688
fixed	EMFIncQuery-LocalSearch	4	SwitchSet	read and check	time	344.405117
fixed	EMFIncQuery-Incremental	8	SwitchSet	read and check	time	526.357238
fixed	EMFIncQuery-LocalSearch	8	SwitchSet	read and check	time	393.372673
fixed	EMFIncQuery-Incremental	16	SwitchSet	read and check	time	367.026443
fixed	EMFIncQuery-LocalSearch	16	SwitchSet	read and check	time	335.331063
fixed	EMFIncQuery-Incremental	32	SwitchSet	read and check	time	742.550248
fixed	EMFIncQuery-LocalSearch	32	SwitchSet	read and check	time	745.474537
fixed	EMFIncQuery-Incremental	64	SwitchSet	read and check	time	1409.785411
fixed	EMFIncQuery-LocalSearch	64	SwitchSet	read and check	time	1337.410146
fixed	EMFIncQuery-Incremental	128	SwitchSet	read and check	time	2723.686899
fixed	EMFIncQuery-LocalSearch	128	SwitchSet	read and check	time	2654.318845
fixed	EMFIncQuery-Incremental	256	SwitchSet	read and check	time	5228.220024
fixed	EMFIncQuery-LocalSearch	256	SwitchSet	read and check	time	5109.74452
fixed	EMFIncQuery-Incremental	512	SwitchSet	read and check	time	10647.262411
fixed	EMFIncQuery-LocalSearch	512	SwitchSet	read and check	time	10255.406911
fixed	EMFIncQuery-Incremental	1024	SwitchSet	read and check	time	21832.349604
fixed	EMFIncQuery-LocalSearch	1024	SwitchSet	read and check	time	21812.854842
fixed	EMFIncQuery-Incremental	2048	SwitchSet	read and check	time	43964.996234
fixed	EMFIncQuery-LocalSearch	2048	SwitchSet	read and check	time	42751.28656
fixed	EMFIncQuery-Incremental	4096	SwitchSet	read and check	time	86172.978543
fixed	EMFIncQuery-LocalSearch	4096	SwitchSet	read and check	time	81218.836356
fixed	EMFIncQuery-Incremental	8192	SwitchSet	read and check	time	214932.335954
fixed	EMFIncQuery-LocalSearch	8192	SwitchSet	read and check	time	205799.651229
proportional	EMFIncQuery-Incremental	1	SwitchSet	read and check	time	202.849318
proportional	EMFIncQuery-LocalSearch	1	SwitchSet	read and check	time	173.902516
proportional	EMFIncQuery-Incremental	2	SwitchSet	read and check	time	236.147014
proportional	EMFIncQuery-LocalSearch	2	SwitchSet	read and check	time	202.472323
proportional	EMFIncQuery-Incremental	4	SwitchSet	read and check	time	429.291008
proportional	EMFIncQuery-LocalSearch	4	SwitchSet	read and check	time	353.470199
proportional	EMFIncQuery-Incremental	8	SwitchSet	read and check	time	448.922723
proportional	EMFIncQuery-LocalSearch	8	SwitchSet	read and check	time	296.550607
proportional	EMFIncQuery-Incremental	16	SwitchSet	read and check	time	377.83214
proportional	EMFIncQuery-LocalSearch	16	SwitchSet	read and check	time	337.867756
proportional	EMFIncQuery-Incremental	32	SwitchSet	read and check	time	733.572509
proportional	EMFIncQuery-LocalSearch	32	SwitchSet	read and check	time	767.643292
proportional	EMFIncQuery-Incremental	64	SwitchSet	read and check	time	1385.439209
proportional	EMFIncQuery-LocalSearch	64	SwitchSet	read and check	time	1342.553532
proportional	EMFIncQuery-Incremental	128	SwitchSet	read and check	time	2735.031563
proportional	EMFIncQuery-LocalSearch	128	SwitchSet	read and check	time	2653.103857
proportional	EMFIncQuery-Incremental	256	SwitchSet	read and check	time	5211.693255
proportional	EMFIncQuery-LocalSearch	256	SwitchSet	read and check	time	5121.656312
proportional	EMFIncQuery-Incremental	512	SwitchSet	read and check	time	10575.249589
proportional	EMFIncQuery-LocalSearch	512	SwitchSet	read and check	time	10265.694798
proportional	EMFIncQuery-Incremental	1024	SwitchSet	read and check	time	21943.124502
proportional	EMFIncQuery-LocalSearch	1024	SwitchSet	read and check	time	21939.726695
proportional	EMFIncQuery-Incremental	2048	SwitchSet	read and check	time	47219.301477
proportional	EMFIncQuery-LocalSearch	2048	SwitchSet	read and check	time	43977.344409
proportional	EMFIncQuery-Incremental	4096	SwitchSet	read and check	time	85771.758384
proportional	EMFIncQuery-LocalSearch	4096	SwitchSet	read and check	time	82030.447963
proportional	EMFIncQuery-Incremental	8192	SwitchSet	read and check	time	213949.725008
proportional	EMFIncQuery-LocalSearch	8192	SwitchSet	read and check	time	208860.208973

Table 9: Benchmark results for the SwitchSet query.

ChangeSet	Tool	Size	Query	PhaseName	MetricName	MetricValue
fixed	EMFIncQuery-Incremental	1	SwitchSet	modify and revalidate	time	0.923453
fixed	EMFIncQuery-LocalSearch	1	SwitchSet	modify and revalidate	time	24.335329
fixed	EMFIncQuery-Incremental	2	SwitchSet	modify and revalidate	time	0.66494
fixed	EMFIncQuery-LocalSearch	2	SwitchSet	modify and revalidate	time	29.480884
fixed	EMFIncQuery-Incremental	4	SwitchSet	modify and revalidate	time	3.230078
fixed	EMFIncQuery-LocalSearch	4	SwitchSet	modify and revalidate	time	28.635818
fixed	EMFIncQuery-Incremental	8	SwitchSet	modify and revalidate	time	6.425558
fixed	EMFIncQuery-LocalSearch	8	SwitchSet	modify and revalidate	time	37.231442
fixed	EMFIncQuery-Incremental	16	SwitchSet	modify and revalidate	time	5.890825
fixed	EMFIncQuery-LocalSearch	16	SwitchSet	modify and revalidate	time	30.382119
fixed	EMFIncQuery-Incremental	32	SwitchSet	modify and revalidate	time	5.277236
fixed	EMFIncQuery-LocalSearch	32	SwitchSet	modify and revalidate	time	42.026298
fixed	EMFIncQuery-Incremental	64	SwitchSet	modify and revalidate	time	5.035648
fixed	EMFIncQuery-LocalSearch	64	SwitchSet	modify and revalidate	time	51.385197
fixed	EMFIncQuery-Incremental	128	SwitchSet	modify and revalidate	time	5.669557
fixed	EMFIncQuery-LocalSearch	128	SwitchSet	modify and revalidate	time	54.736698
fixed	EMFIncQuery-Incremental	256	SwitchSet	modify and revalidate	time	5.674425
fixed	EMFIncQuery-LocalSearch	256	SwitchSet	modify and revalidate	time	92.260942
fixed	EMFIncQuery-Incremental	512	SwitchSet	modify and revalidate	time	4.836251
fixed	EMFIncQuery-LocalSearch	512	SwitchSet	modify and revalidate	time	133.983525
fixed	EMFIncQuery-Incremental	1024	SwitchSet	modify and revalidate	time	5.741573
fixed	EMFIncQuery-LocalSearch	1024	SwitchSet	modify and revalidate	time	266.665015
fixed	EMFIncQuery-Incremental	2048	SwitchSet	modify and revalidate	time	6.29377
fixed	EMFIncQuery-LocalSearch	2048	SwitchSet	modify and revalidate	time	502.177003
fixed	EMFIncQuery-Incremental	4096	SwitchSet	modify and revalidate	time	6.121537
fixed	EMFIncQuery-LocalSearch	4096	SwitchSet	modify and revalidate	time	991.881967
fixed	EMFIncQuery-Incremental	8192	SwitchSet	modify and revalidate	time	6.838978
fixed	EMFIncQuery-LocalSearch	8192	SwitchSet	modify and revalidate	time	2893.51237
proportional	EMFIncQuery-Incremental	1	SwitchSet	modify and revalidate	time	0.037554
proportional	EMFIncQuery-LocalSearch	1	SwitchSet	modify and revalidate	time	24.544257
proportional	EMFIncQuery-Incremental	2	SwitchSet	modify and revalidate	time	0.040755
proportional	EMFIncQuery-LocalSearch	2	SwitchSet	modify and revalidate	time	32.413495
proportional	EMFIncQuery-Incremental	4	SwitchSet	modify and revalidate	time	0.854157
proportional	EMFIncQuery-LocalSearch	4	SwitchSet	modify and revalidate	time	29.179642
proportional	EMFIncQuery-Incremental	8	SwitchSet	modify and revalidate	time	3.498142
proportional	EMFIncQuery-LocalSearch	8	SwitchSet	modify and revalidate	time	41.66948
proportional	EMFIncQuery-Incremental	16	SwitchSet	modify and revalidate	time	4.04174
proportional	EMFIncQuery-LocalSearch	16	SwitchSet	modify and revalidate	time	33.742092
proportional	EMFIncQuery-Incremental	32	SwitchSet	modify and revalidate	time	5.538361
proportional	EMFIncQuery-LocalSearch	32	SwitchSet	modify and revalidate	time	42.779298
proportional	EMFIncQuery-Incremental	64	SwitchSet	modify and revalidate	time	10.647013
proportional	EMFIncQuery-LocalSearch	64	SwitchSet	modify and revalidate	time	58.024174
proportional	EMFIncQuery-Incremental	128	SwitchSet	modify and revalidate	time	19.033587
proportional	EMFIncQuery-LocalSearch	128	SwitchSet	modify and revalidate	time	57.20849
proportional	EMFIncQuery-Incremental	256	SwitchSet	modify and revalidate	time	34.238173
proportional	EMFIncQuery-LocalSearch	256	SwitchSet	modify and revalidate	time	96.377388
proportional	EMFIncQuery-Incremental	512	SwitchSet	modify and revalidate	time	47.63571
proportional	EMFIncQuery-LocalSearch	512	SwitchSet	modify and revalidate	time	138.035385
proportional	EMFIncQuery-Incremental	1024	SwitchSet	modify and revalidate	time	73.157516
proportional	EMFIncQuery-LocalSearch	1024	SwitchSet	modify and revalidate	time	237.37585
proportional	EMFIncQuery-Incremental	2048	SwitchSet	modify and revalidate	time	78.99769
proportional	EMFIncQuery-LocalSearch	2048	SwitchSet	modify and revalidate	time	438.623374
proportional	EMFIncQuery-Incremental	4096	SwitchSet	modify and revalidate	time	175.037324
proportional	EMFIncQuery-LocalSearch	4096	SwitchSet	modify and revalidate	time	876.239088
proportional	EMFIncQuery-Incremental	8192	SwitchSet	modify and revalidate	time	324.747253
proportional	EMFIncQuery-LocalSearch	8192	SwitchSet	modify and revalidate	time	2066.011621

Table 10: Benchmark results for the SwitchSet query.