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Experimental Evaluation for Optimizing Data-Flow for Inter-Organizational Processes

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Abstract This paper describes in detail the experimental evaluation that we conducted to evaluate our approach to automatic data-flow generation in inter-organizational processes. Here we describe our evaluation goals, the setting, and present the results of the experiments. We present the data collected through the experiments in the form of tables and graphics; we additionally provide a brief explanation of the reported numbers.

1 Evaluation

1.1 Evaluation Goals

The proposed composite algorithm can generate augmentations adhering to any safeness class. Depending on the selected safeness class it competes with the fully transitive (no-restriction), the early direct-send (weak dynamic) and the late direct send (strong dynamic) base-line approaches. The primer goal of the evaluation is therefore to assess the α, β and γ values of the generated solutions of the composite algorithm in comparison to the base-line approaches. However, the achievable measure scores are influenced by various dimensions of processes: The topology, the number of actors, the number of steps reading from and writing to variables. Therefore, multi-dimensional experiments are required. Finally, the scalability in terms of size and complexity of the input process models is an important issue. We have therefore conducted an experimental evaluation with the following evaluation goals:

- *EG1* How do the generated solutions of the heuristic approach compete with the base-line approaches in terms of measure scores?

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- *EG2* How do the dimensions topology, size, number of actors, number of activities reading from and writing to variables influence the achievable measure scores?
- *EG3* Does the approach scale to provide reasonable performance for relevant classes of real world processes?

1.2 Evaluation Setting

We have implemented our heuristic algorithm and executed this implementation with different restriction levels over a number of process models, calculating the values of parameters α, β, and γ for each generated solution. We have also implemented algortihms that realize the base-line approaches *data-flow follows control flow*, *direct late send*, and *direct early send*, and ran them over the same set of process models, calculating the values of α, β, and γ as well. Finally we analyzed and compared the values of the parameters for the generated base-line solutions with the ones of the heuristic algorithm.

All the algorithms implementations have been written in Java 1.8. The evaluation has been run on a Windows 10 virtual machine, equipped with an Intel(R) Xeon(R) E5-2630 processor with 2.20GHz clock frequency, and 32 GB of memory.

1.2.1 Data-Set

The process models used as input for the algorithms have been implemented adopting a hierarchical representation that allows us to have by design full-blocked-structured processes. For the gathering of the input processes we generated process topologies with a fixed number of activity steps, and with a varying number of complex steps (sequences of steps, xor-blocks and par-blocks). We also varied the position and nesting level of complex steps from one process to another.

Since we aimed at the most comprehensive coverage of process types for the algorithms evaluation, we identified a list of characteristics which determine distinct classes of processes. The combination of these characteristics determines what we call the *complexity* of a process:

- number of activity steps,
- number of complex steps (xor- and par-blocks),
- nesting level of complex steps,
- number of process participants,
- number of activities reading a variable,
- number of activities writing a variable, and
- number of steps in charge to a specific participant.

For our experiments we generated processes that read and write to a single variable, in order to better evaluate the impact of the aforementioned factors in isolation. This is without loss of generality, since processes manipulating

Class	Min # GW	Max # GW	Avg # GW	# Activities
S	6	10	7	16
M	10	16	12	50
L	22	26	24	100

Table 1 Characteristics of the topologies for the different classes: minimum, maximum and average number of gateways, and number of activity steps.

Topology	# XOR blocks	# PAR blocks	# Activities
Sxx_00	5	3	16
Sxx_01	1	6	16
Sxx_02	3	5	16
Sxx_03	1	5	16
Sxx_04	5	3	16
Sxx_05	6	1	16
Sxx_06	5	3	16
Sxx_07	3	3	16
Sxx_08	6	4	16
Sxx_09	3	6	16

Table 2 Characteristics of the topologies for the S class.

several variables can be projected into multiple processes, one per each variable. The algorithms can then be executed on the projected processes and the results merged at the end.

We defined three classes of process topologies of different complexities, namely *S*, *M*, and *L*. Processes in the *S* class have 16 activity steps; processes in the *M* class have 50 activity steps; processes in the *L* class have 100 activity steps.

As for the process partners, their number differs from one class to another, and within the classes. For the *S* class, we generated three subclasses, each containing the same set of topologies: one with 2 (*S02*), one with 3 (*S03*) and one with 4 (*S04*) partners. For the *M* class, one with 5 partners (*M05*), the second one with 10 partners (*M10*), and the third one with 15 partners (*M15*). Topologies in the *L* class have 10 (*L10*), 20 (*L20*) and 30 (*L30*) partners.

For each class, we generated 10 different topologies (*Sxx_00-Sxx_09*, *Mxx_00-Mxx_09*, *Lxx_00-Lxx_09*). Topologies in the *S* class have on average 7 xor- and par-blocks combined, with a minimum of 6 and a maximum of 10. For topologies in the *M* class, the average number of xor- and par-blocks combined is 12, with a minimum of 10 and a maximum of 16. For topologies in the *L* class the average number of xor- and par-blocks combined is 24, with a minimum of 22 and a maximum of 26. Table 1 summarizes the characteristics of the topologies in the different classes. Please refer to tables 2, 3, and 4 for a detailed description of the characteristics of each topology in each class.

For each of the topologies, we varied the number of steps reading and writing to a variable. In particular, we first generated 5 different subclasses of

Topology	# XOR blocks	# PAR blocks	# Activities
Mxx_00	3	7	50
Mxx_01	6	7	50
Mxx_02	8	8	50
Mxx_03	10	4	50
Mxx_04	8	3	50
Mxx_05	7	6	50
Mxx_06	7	4	50
Mxx_07	10	1	50
Mxx_08	5	8	50
Mxx_09	5	8	50

Table 3 Characteristics of the topologies for the M class.

Topology	# XOR blocks	# PAR blocks	# Activities
Lxx_00	8	14	100
Lxx_01	9	14	100
Lxx_02	10	14	100
Lxx_03	14	12	100
Lxx_04	11	13	100
Lxx_05	11	12	100
Lxx_06	10	12	100
Lxx_07	14	11	100
Lxx_08	15	11	100
Lxx_09	17	8	100

Table 4 Characteristics of the topologies for the L class.

correct processes by randomly assigning 20%, 40%, 60%, 80%, and 100% of the steps as readers. For each of these subclasses we then randomly assigned 20%, 40%, 60%, 80%, and 100% of the reading steps as writers. The underlying assumption was that if a step is writing to a variable, it must also be a reader of it in the first place. Additionally, we assume that the first step of a process is always in charge of the initialization of the variable, which makes it a writer. This phase led to 25 processes for each topology, which differ from each other in the assignment of steps reading and writing to the variable.

Finally, for each of the 25 processes per topology, we performed 10 random assignments of process partners to the steps, which led us to a body of 7500 different process models for the S class, 7500 for the M class, and 7500 for the L class. The tree structure in Fig.1 shows how a process model has been obtained with our process generation approach.

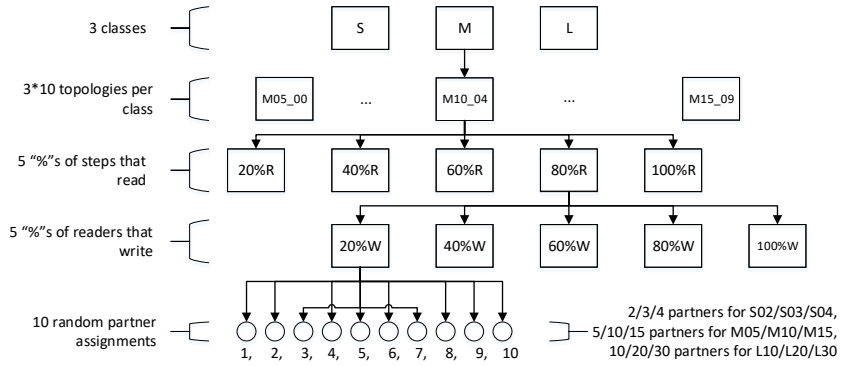


Fig. 1 Test processes generation tree

1.3 Structure of the Archive

For each subclass of processes the archive contains two files: a `.csv` containing the raw measure scores as produced by the algorithm and a `.xlsx` one. The `.xlsx` files contain the same data as the `.csv` ones, but presented in a more human-readable form. Each line corresponds to a process instance, and in the columns the corresponding percentages of readers and writers, the number of partners, the measure scores for α, β, γ, the times of execution (measured in milliseconds) and memory usage (measured in Megabytes) are reported for each algorithm execution. In addition, the `.xlsx` files contain sheets with pivot tables and graphics reporting the gains in α and β for specific restrictions of the heuristic approach versus specific base-lines. Three additional `.xlsx` files, one per class, summarize the data for the corresponding subclasses. For the readers' convenience, this paper summarizes the data contained in the `.xlsx` files and reports the pivot tables and graphics. The archive contains also a compressed file with the textual representations of the processes used for the evaluation and of the corresponding generated augmentations.

1.4 Overall Measure Scores

In the next we will use the following abbreviations to refer to the different modes of execution of the heuristic: $H-UN$ for the unrestricted mode, $H-SN$ for the statically safe mode, $H-WDN$ for the weak dynamically safe mode, and $H-SDN$ for the strong dynamically safe mode. We will refer to the base-line approach *data-flow follows control-flow* as $B1$, to the late send approach as $B2$, and to the early send approach as $B3$.

We now look at the values of α, β, and γ for the solutions obtained from the executions of the different implemented algorithms, by first considering the general trends, abstracting from the specific classes.

Algorithm	α	β	γ
B1	0.00	54.54	0.00
H-UN	0.00	12.16	12.94
H-SN	0.97	10.10	11.61
H-WDN	2.76	7.60	11.18
H-SDN	3.10	7.28	11.37
B2	4.81	7.28	10.68
B3	19.55	23.59	6.35

Table 5 Average values of α, β, and γ for the execution of the different algorithms over the 22500 processes of all classes.

Table 5 shows the average values for α, β, and γ obtained with the different algorithms executions over all the generated processes.

A general trend is the very high value of β for the execution of $B1$, which is the highest among all the algorithms. This is opposed to the values of α and γ which are always 0 for $B1$. This augmentation completely integrates data- and control-flow, and does not take into account decision variables. An algorithm that similarly to $B1$ aims at the integration of data- and control-flow is $H-UN$. The β value induced by $H-UN$ is significantly lower than the one of $B1$; it however induces an increased γ value compared to $B1$.

The lowest β is returned by solutions generated both by $B2$ and $H-SDN$; while the two algorithms are also very similar in the resulting γ values, they differ significantly when it comes to α, which, proportionally, is much lower for $H-SDN$.

Values corresponding to solutions generated by $H-SN$ and $H-WDN$ are collocated between the ones of $H-UN$ and $H-SDN$. In particular, as the restriction level increases, the α values increase and the β ones decrease.

To answer to our evaluation goal *EG1* we now compare against each other the values obtained from base-lines $B1$ and $B2$, and from the nonrestricted and most restricted modes of operation of the heuristic.

1. *Fully transitive transmission vs. Heuristic, unrestricted*
   Both the fully transitive approach and $H-UN$ augment a process in a way such that all the partners subsequent to a variable writer W are recipients of the value written by W. Our experiments show that the reduction in the value of β is considerably high, being on average 78%. On the other hand, $H-UN$ brings on average an increase of γ from 0 to 12.94.
2. *Direct late send vs. Heuristic, strong dynamically safe*
   Both $B2$ and $H-SDN$ produce solutions with the very same β value. In our experiments, however, $H-SDN$ provided results with an observed average α gain of 36%. Regarding γ, our heuristic approach reaches values which are very close to the ones of the base-line, being 11.37 the score for $H-SDN$ and 10.68 the one for $B2$.

1.5 Measure Scores by Process Class

In this and the following subsections we focus our attention on the results obtained for each class, devoting particular attention on the M class for what concerns the differences induced by the number of partners.

Algorithm	α	β	γ
B1	0.00	16.17	0.00
H-UN	0.00	1.82	2.23
H-SN	0.09	1.72	2.13
H-WDN	0.24	1.58	2.12
H-SDN	0.27	1.55	2.13
B2	0.73	1.55	2.08
B3	2.29	3.86	0.79

Table 6 Average values of α, β, and γ for the execution of the different algorithms over the 7500 processes of class *S*.

Algorithm	α	β	γ
B1	0.00	16.56	0.00
H-UN	0.00	1.79	0.03
H-SN	0.00	1.79	0.03
H-WDN	0.00	1.79	0.03
H-SDN	0.00	1.79	0.03
B2	0.50	1.79	0.04
B3	1.16	2.94	0.02

Table 7 Average values of α, β, and γ for the execution of the different algorithms over the 2500 processes of class *S02*.

Algorithm	α	β	γ
B1	0.00	16.78	0.00
H-UN	0.00	1.54	6.17
H-SN	0.06	1.48	5.94
H-WDN	0.22	1.33	5.84
H-SDN	0.26	1.29	5.85
B2	0.70	1.29	5.69
B3	2.69	4.37	2.20

Table 8 Average values of α, β, and γ for the execution of the different algorithms over the 2500 processes of class *S03*.

Algorithm	α	β	γ
B1	0.00	15.16	0.00
H-UN	0.00	2.14	0.49
H-SN	0.22	1.89	0.42
H-WDN	0.48	1.62	0.48
H-SDN	0.54	1.56	0.50
B2	0.98	1.56	0.51
B3	3.02	4.27	0.14

Table 9 Average values of α, β, and γ for the execution of the different algorithms over the 2500 processes of class *S04*.

For all the processes in the S class, on average, we obtained the results that are summarized in Table 6. One first observation that can be made on the table is that there is an enormous reduction (86%) in the value of β when moving from the fully transitive solution to the unrestricted heuristic algorithm. For the processes of class S, our experiments showed that on average the increase of γ with respect to the base-line is 2.23.

When applying our heuristic algorithm with more restricted settings, we experienced an increase in the value of α and a decrease in the value of β in comparison to the unrestricted case. The value of β for the most restrictive case (strong dynamically safe) is exactly the same as that one for the late send algorithm. The advantage of the heuristic over the base-line, though, is shown in the values of α: 0.27 against 0.73, which is a gain of 63%.

Algorithm	α	β	γ
B1	0.00	53.54	0.00
H-UN	0.00	12.49	17.53
H-SN	0.83	10.91	16.27
H-WDN	2.59	8.50	15.57
H-SDN	3.03	8.08	15.77
B2	5.00	8.08	14.72
B3	18.44	23.07	9.81

Table 10 Average values of α, β, and γ for the execution of the different algorithms over the 7500 processes of class *M*.

Table 10 shows the measure scores for the execution of the algorithms over processes of class *M*. The fully transitive solutions are the ones with the highest β value. In contrast to this, the unrestricted heuristic provides much lower values for β, but an increase in γ. With higher restriction levels, the heuristic shows an increase in α and a decrease in β, reaching the same β value as the late send approach with the strong dynamic safeness class.

It is interesting to observe the influence of the number of partners over the measure scores (please refer to tables 11, 12, and 13 for details). In particular,

Algorithm	α	β	γ
B1	0.00	53.29	0.00
H-UN	0.00	9.04	18.13
H-SN	0.13	8.86	17.72
H-WDN	1.27	7.45	16.52
H-SDN	1.76	6.99	16.65
B2	3.71	6.99	15.58
B3	12.58	17.75	11.08

Table 11 Average values of α, β, and γ for the execution of the different algorithms over the 2500 processes of class *M05*.

Algorithm	α	β	γ
B1	0.00	54.50	0.00
H-UN	0.00	13.31	28.15
H-SN	0.80	11.78	24.95
H-WDN	2.88	8.86	22.89
H-SDN	3.34	8.40	22.97
B2	5.37	8.40	21.60
B3	21.25	25.79	14.88

Table 12 Average values of α, β, and γ for the execution of the different algorithms over the 2500 processes of class *M10*.

Algorithm	α	β	γ
B1	0.00	52.82	0.00
H-UN	0.00	15.11	6.39
H-SN	1.55	12.10	6.17
H-WDN	3.62	9.21	7.33
H-SDN	3.99	8.86	7.71
B2	5.92	8.86	6.96
B3	20.87	25.02	3.47

Table 13 Average values of α, β, and γ for the execution of the different algorithms over the 2500 processes of class *M15*.

when the number of partners is low, the β gain of $H-UN$ compared to $B1$ is higher; as the number of partners increases the β reduction is less effective. This can be easily observed by comparing the histograms in Fig. 2, 3, and 4. The same observation is valid also for the α gain of $H-SDN$ against $B2$: Fig. 5, 6, and 7 can be compared against each other to verify the influence of the number of partners over the α gain.

In Table 14 we show the measure scores for the execution of the algorithms over processes of class L. Again the fully transitive solution brings the highest β value, which gets significantly lower by applying the heuristic algorithm in the unrestricted mode. As the restriction level is raised, β decreases until it

Algorithm	α	β	γ
B1	0.00	93.91	0.00
H-UN	0.00	22.17	19.05
H-SN	1.99	17.68	16.43
H-WDN	5.46	12.71	15.85
H-SDN	5.99	12.22	16.21
B2	8.72	12.22	15.25
B3	37.93	43.83	8.45

Table 14 Average values of α, β, and γ for the execution of the different algorithms over the 7500 processes of class *L*.

Algorithm	α	β	γ
B1	0.00	95.09	0.00
H-UN	0.00	18.27	6.51
H-SN	0.65	17.04	6.15
H-WDN	4.20	12.05	6.71
H-SDN	4.93	11.37	7.03
B2	7.70	11.37	6.36
B3	35.09	42.35	3.40

Table 15 Average values of α, β, and γ for the execution of the different algorithms over the 2500 processes of class *L10*.

Algorithm	α	β	γ
B1	0.00	97.70	0.00
H-UN	0.00	23.79	25.80
H-SN	2.16	18.86	21.88
H-WDN	5.95	13.25	19.98
H-SDN	6.43	12.81	20.29
B2	9.36	12.81	19.14
B3	39.86	45.38	10.87

Table 16 Average values of α, β, and γ for the execution of the different algorithms over the 2500 processes of class *L20*.

reaches an average of 11.37, which is the same as for the late send. At the same time, the value of α gets higher as the safeness class gets more restrictive, but does not reach the same value as for the late send.

1.6 Measure Scores by Number of Readers and Writers

In this subsection we analyze the measure scores by grouping the processes of *M05*, *M10*, and *M15* by number of readers and writers, to assess how these characteristics influence the resulting values of α, β, and γ. Similar observations can be made on the results for classes *S* and *L*.

Algorithm	α	β	γ
B1	0.00	88.94	0.00
H-UN	0.00	24.47	24.85
H-SN	3.16	17.14	21.25
H-WDN	6.23	12.83	20.85
H-SDN	6.60	12.48	21.31
B2	9.10	12.48	20.25
B3	38.84	43.77	11.07

Table 17 Average values of α, β, and γ for the execution of the different algorithms over the 2500 processes of class *L30*.

	20% R	**40% R**	**60% R**	**80% R**	**100% R**	**Total**
20% W	84.29%	92.29%	91.25%	89.23%	91.52%	89.72%
40% W	85.23%	92.41%	90.54%	88.91%	87.31%	88.88%
60% W	84.55%	90.68%	88.83%	86.89%	84.33%	87.06%
80% W	83.50%	89.93%	87.10%	83.90%	81.42%	85.17%
100% W	81.50%	89.56%	84.65%	81.82%	79.00%	83.31%
Total	83.82%	90.97%	88.48%	86.15%	84.72%	86.83%

Table 18 Average reduction of β of $H-UN$ compared to $B1$ for processes in class *S02*, by % of readers and % of writers.

1.6.1 Decrease in β of heuristic approach vs Baseline B1

As shown in Fig. 2, for processes in *M05*, in the broad range of 40% readers to 80% readers and 20 to 100% writers, the decreases in β range from 68.97% to 92.68%. For 20% readers, the β gain spans from 89.05% to 92.02%. The lowest gains are those relative to processes with 100% writers, but still good results were possible, with a minimum β decrease of 64.97%.

For processes in *M10*, as can be seen in Fig. 3, in the broad range of 40% readers to 80% readers and 20 to 100% writers, the decreases in β span from 60.41% to 85.04%. For 20% readers, we observe a gain in β from 87.03% to 89.93%. As for *M05*, also for this class of processes the lowest β reduction is found in the case of 100% writers, with a minimum gain of 54.25%.

Fig. 4 shows that for processes in *M15*, in the broad range of 40% readers to 80% readers and 20 to 100% writers very good average decreases in β of 61.26% to 75.50% were achieved. The case of 20% readers resulted in average decreases of the β value of 79.59% to 83.7%. The extreme case of 100% writers strongly reduces the utility of exploiting tunnels. Tunnels can only occur between split and join nodes but non between activities. However, still reasonable decreases of β of 51.75% to 63.93% were achieved.

An overall trend is that the higher the number of writers or readers, the lower the advantage of our heuristic algorithm. However, the minimal average decrease in β is still 64.97% for *M05*, 54.25% for *M10*, and 51.75% for *M15*.

	20% R	**40% R**	**60% R**	**80% R**	**100% R**	**Total**
20% W	94.42%	92.69%	91.23%	90.05%	88.74%	91.43%
40% W	94.44%	92.61%	89.13%	89.06%	86.46%	90.34%
60% W	94.19%	91.60%	88.19%	88.07%	87.36%	89.88%
80% W	95.20%	92.20%	88.22%	85.97%	84.48%	89.21%
100% W	95.58%	91.38%	87.99%	83.95%	84.31%	88.64%
Total	94.76%	92.10%	88.95%	87.42%	86.27%	89.90%

Table 19 Average reduction of β of $H - UN$ compared to $B1$ for processes in class *S03*, by % of readers and % of writers.

	20% R	**40% R**	**60% R**	**80% R**	**100% R**	**Total**
20% W	86.63%	86.31%	82.72%	85.51%	88.37%	85.91%
40% W	87.16%	87.17%	83.56%	84.03%	87.69%	85.92%
60% W	88.60%	85.08%	81.24%	81.73%	84.52%	84.23%
80% W	85.56%	83.50%	80.30%	79.30%	78.55%	81.44%
100% W	87.96%	81.60%	79.80%	80.65%	76.37%	81.27%
Total	87.18%	84.73%	81.52%	82.24%	83.10%	83.76%

Table 20 Average reduction of β of $H - UN$ compared to $B1$ for processes in class *S04*, by % of readers and % of writers.

	20% R	**40% R**	**60% R**	**80% R**	**100% R**	**Total**
20% W	91.59%	92.68%	88.44%	83.11%	82.12%	87.59%
40% W	92.02%	90.65%	86.02%	78.65%	76.41%	84.75%
60% W	90.89%	88.77%	82.91%	75.03%	71.14%	81.75%
80% W	89.48%	86.01%	80.60%	71.82%	67.30%	79.04%
100% W	89.05%	85.36%	78.81%	68.97%	64.97%	77.43%
Total	90.61%	88.69%	83.35%	75.52%	72.39%	82.11%

Table 21 Average reduction of β of $H - UN$ compared to $B1$ for processes in class *M05*, by % of readers and % of writers.

	20% R	**40% R**	**60% R**	**80% R**	**100% R**	**Total**
20% W	89.81%	83.69%	76.67%	75.56%	70.18%	79.18%
40% W	88.73%	81.58%	72.64%	69.22%	63.67%	75.17%
60% W	88.41%	78.60%	69.63%	66.95%	59.34%	72.59%
80% W	88.24%	77.29%	68.00%	63.77%	56.89%	70.84%
100% W	87.31%	76.14%	65.84%	62.17%	54.25%	69.14%
Total	88.50%	79.46%	70.56%	67.53%	60.87%	73.38%

Table 22 Average reduction of β of $H - UN$ compared to $B1$ for processes in class *M10*, by % of readers and % of writers.

	20% R	**40% R**	**60% R**	**80% R**	**100% R**	**Total**
20% W	83.62%	75.59%	73.30%	75.96%	63.93%	74.48%
40% W	83.68%	74.02%	68.73%	71.52%	59.72%	71.53%
60% W	82.36%	71.47%	65.33%	65.96%	57.01%	68.42%
80% W	81.84%	69.62%	63.89%	64.42%	53.97%	66.75%
100% W	79.51%	66.44%	62.11%	61.26%	51.75%	64.21%
Total	82.20%	71.43%	66.67%	67.82%	57.28%	69.08%

Table 23 Average reduction of β of $H - UN$ compared to $B1$ for processes in class *M15*, by % of readers and % of writers.

	20% R	**40% R**	**60% R**	**80% R**	**100% R**	**Total**
20% W	90.72%	89.07%	80.60%	82.73%	80.76%	84.78%
40% W	90.16%	86.79%	76.43%	77.82%	73.98%	81.03%
60% W	89.05%	83.67%	73.72%	73.19%	68.04%	77.53%
80% W	88.00%	82.24%	70.51%	69.38%	64.29%	74.88%
100% W	87.17%	80.24%	68.18%	66.52%	62.01%	72.82%
Total	89.02%	84.40%	73.89%	73.93%	69.82%	78.21%

Table 24 Average reduction of β of $H - UN$ compared to $B1$ for processes in class *L10*, by % of readers and % of writers.

	% R	**40% R**	**60% R**	**80% R**	**100% R**	**Total**
20% W	87.15%	83.79%	78.99%	73.66%	70.49%	78.82%
40% W	85.90%	81.24%	74.68%	70.26%	65.02%	75.42%
60% W	85.23%	78.18%	70.22%	64.95%	60.43%	71.80%
80% W	84.02%	77.24%	67.36%	63.15%	58.83%	70.12%
100% W	83.12%	75.01%	64.86%	61.14%	55.52%	67.93%
Total	85.09%	79.09%	71.22%	66.63%	62.06%	72.82%

Table 25 Average reduction of β of $H - UN$ compared to $B1$ for processes in class *L20*, by % of readers and % of writers.

	20% R	**40% R**	**60% R**	**80% R**	**100% R**	**Total**
20% W	77.30%	78.68%	75.12%	70.84%	69.54%	74.30%
40% W	75.28%	75.32%	68.23%	67.58%	64.72%	70.23%
60% W	73.68%	73.00%	64.19%	64.94%	61.26%	67.41%
80% W	73.39%	69.98%	61.82%	62.52%	59.16%	65.38%
100% W	74.06%	69.33%	60.33%	58.66%	57.23%	63.92%
Total	74.74%	73.26%	65.94%	64.91%	62.38%	68.25%

Table 26 Average reduction of β of $H - UN$ compared to $B1$ for processes in class *L30*, by % of readers and % of writers.

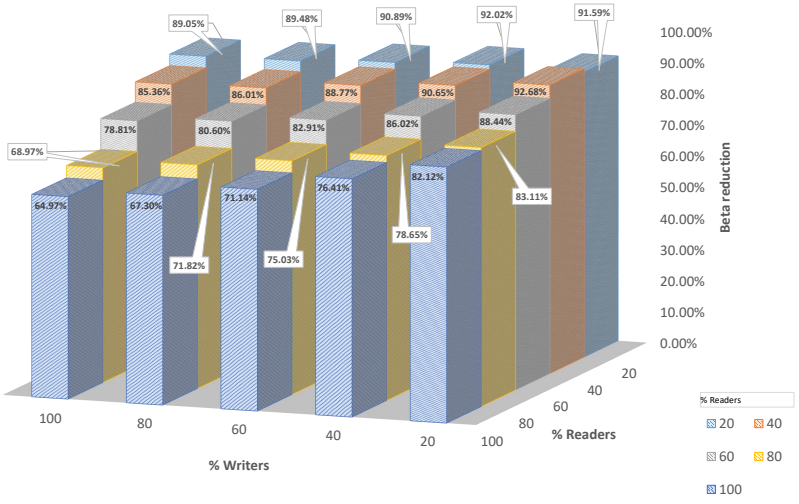


Fig. 2 Average values of β reduction from $B1$ to $H-UN$ for the processes of class *M05*.

	20% R	**40% R**	**60% R**	**80% R**	**100% R**	**Total**
20% W	21.00%	53.00%	60.00%	55.00%	48.00%	47.40%
40% W	18.00%	47.00%	53.00%	62.00%	70.00%	50.00%
60% W	27.00%	56.00%	62.00%	67.00%	73.00%	57.00%
80% W	23.00%	53.00%	63.00%	71.00%	69.00%	55.80%
100% W	37.00%	45.00%	68.00%	70.00%	72.00%	58.40%
Total	25.20%	50.80%	61.20%	65.00%	66.40%	53.72%

Table 27 Average reduction of α of $H-SDN$ compared to $B2$ for processes in class *S02*, by % of readers and % of writers.

1.6.2 Decrease in α of heuristic approach vs Baseline B2

Comparing $H-SDN$ with $B2$ we observed a significant decrease in α: we now take a closer look at the reduction trend as the number of readers and writers changes. A clear trend we can observe is that the more readers there are in a process, the better the α gain for $H-SDN$. In particular we see that for *M05*, *M10* and *M15* the gain is significant in the range 80 to 100% readers, with peaks of 75.84%, 69.66%, and 64.42%, respectively. On the other hand, more writers follows worse result. This is clearly visible in the 100% writers case, independently from the number of readers. The gain induced by tunnels is almost all lost, being an average of 7.51% (*M15*) the worst α gain.

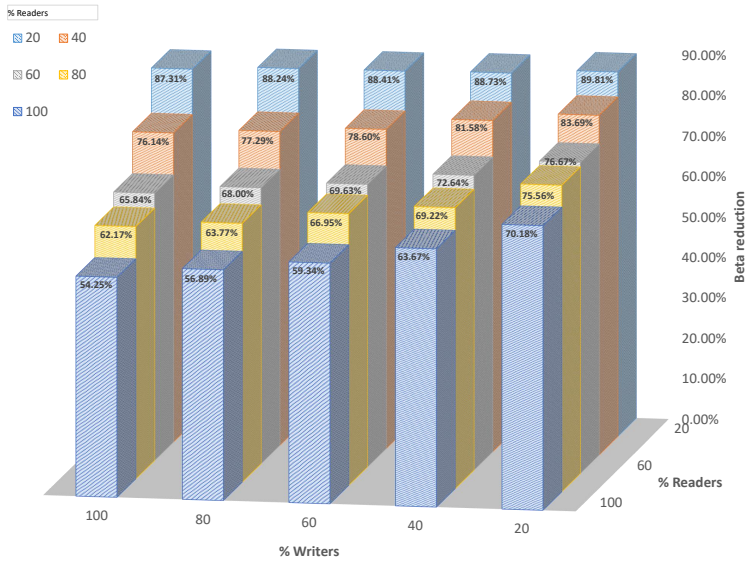


Fig. 3 Average values of β reduction from $B1$ to $H-UN$ for the processes of class *M10*.

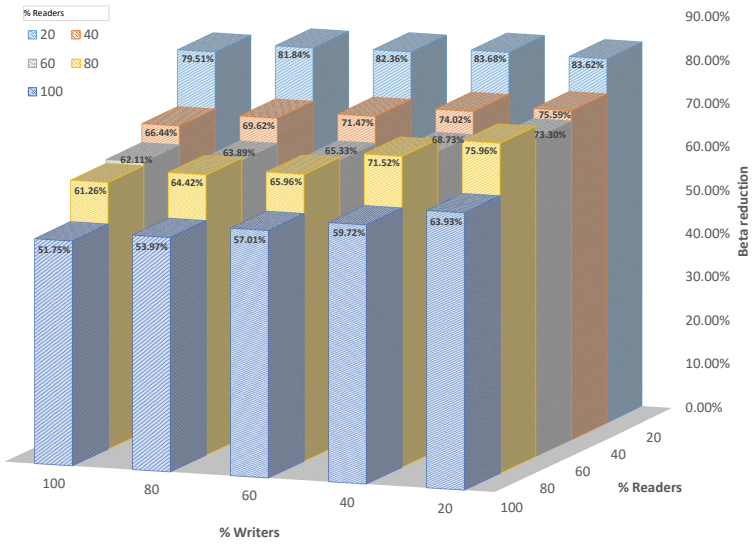


Fig. 4 Average values of β reduction from $B1$ to $H-UN$ for the processes of class *M15*.

	20% R	**40% R**	**60% R**	**80% R**	**100% R**	**Total**
20% W	29.54%	43.81%	67.87%	60.74%	57.63%	51.92%
40% W	29.14%	42.83%	50.61%	55.83%	61.02%	47.89%
60% W	23.83%	52.81%	47.11%	54.85%	61.25%	47.97%
80% W	28.00%	36.33%	43.47%	53.61%	44.23%	41.13%
100% W	29.70%	46.15%	49.11%	47.71%	50.33%	44.60%
Total	28.04%	44.39%	51.63%	54.55%	54.89%	46.70%

Table 28 Average reduction of α of $H-SDN$ compared to $B2$ for processes in class *S03*, by % of readers and % of writers.

	20% R	**40% R**	**60% R**	**80% R**	**100% R**	**Total**
20% W	29.81%	42.18%	45.59%	47.01%	58.10%	44.54%
40% W	30.43%	48.84%	40.64%	46.54%	57.00%	44.69%
60% W	32.40%	42.00%	31.32%	37.85%	51.30%	38.97%
80% W	29.29%	31.17%	34.59%	38.29%	41.11%	34.89%
100% W	28.59%	27.89%	35.66%	34.41%	32.86%	31.88%
Total	30.10%	38.42%	37.56%	40.82%	48.08%	39.00%

Table 29 Average reduction of α of $H-SDN$ compared to $B2$ for processes in class *S04*, by % of readers and % of writers.

	20% R	**40% R**	**60% R**	**80% R**	**100% R**	**Total**
20% W	55.61%	67.56%	65.70%	75.84%	75.47%	68.04%
40% W	50.49%	56.07%	57.38%	63.60%	70.06%	59.52%
60% W	49.96%	50.21%	49.21%	54.34%	61.39%	53.02%
80% W	40.67%	34.15%	37.52%	44.40%	45.51%	40.45%
100% W	36.64%	32.14%	27.16%	25.68%	24.46%	29.21%
Total	46.67%	48.03%	47.39%	52.77%	55.38%	50.05%

Table 30 Average reduction of α of $H-SDN$ compared to $B2$ for processes in class *M05*, by % of readers and % of writers.

	20% R	**40% R**	**60% R**	**80% R**	**100% R**	**Total**
20% W	32.37%	42.37%	47.67%	60.12%	69.66%	50.44%
40% W	22.47%	34.74%	38.91%	49.79%	59.95%	41.17%
60% W	22.21%	28.68%	29.10%	42.83%	50.41%	34.65%
80% W	21.13%	21.87%	21.13%	29.75%	36.68%	26.11%
100% W	16.84%	13.01%	12.71%	11.24%	10.38%	12.84%
Total	23.00%	28.13%	29.90%	38.75%	45.41%	33.04%

Table 31 Average reduction of α of $H-SDN$ compared to $B2$ for processes in class *M10*, by % of readers and % of writers.

	20% R	**40% R**	**60% R**	**80% R**	**100% R**	**Total**
20% W	23.55%	26.59%	46.03%	54.32%	64.42%	42.98%
40% W	16.28%	24.21%	39.45%	43.54%	54.92%	35.68%
60% W	20.10%	17.20%	29.59%	33.99%	46.15%	29.41%
80% W	8.66%	11.47%	18.67%	20.37%	28.24%	17.48%
100% W	8.06%	7.90%	6.91%	6.26%	8.42%	7.51%
Total	15.33%	17.48%	28.13%	31.70%	40.43%	26.61%

Table 32 Average reduction of α of $H - SDN$ compared to $B2$ for processes in class *M15*, by % of readers and % of writers.

	20% R	**40% R**	**60% R**	**80% R**	**100% R**	**Total**
20% W	36.40%	44.98%	49.73%	61.20%	66.95%	51.85%
40% W	28.41%	35.78%	36.04%	50.11%	54.54%	40.98%
60% W	23.60%	27.11%	28.36%	40.60%	42.46%	32.43%
80% W	17.29%	23.01%	21.29%	31.07%	27.20%	23.97%
100% W	13.59%	12.27%	11.85%	11.13%	10.60%	11.89%
Total	23.86%	28.63%	29.45%	38.82%	40.35%	32.22%

Table 33 Average reduction of α of $H - SDN$ compared to $B2$ for processes in class *L10*, by % of readers and % of writers.

	20% R	**40% R**	**60% R**	**80% R**	**100% R**	**Total**
20% W	25.65%	31.99%	46.22%	52.96%	56.33%	42.63%
40% W	20.07%	26.14%	36.65%	45.59%	45.71%	34.83%
60% W	16.72%	18.15%	28.27%	35.33%	35.92%	26.88%
80% W	12.13%	10.53%	20.39%	23.88%	26.69%	18.72%
100% W	10.21%	7.83%	7.54%	7.04%	7.12%	7.95%
Total	16.95%	18.93%	27.81%	32.96%	34.35%	26.20%

Table 34 Average reduction of α of $H - SDN$ compared to $B2$ for processes in class *L20*, by % of readers and % of writers.

	20% R	**40% R**	**60% R**	**80% R**	**100% R**	**Total**
20% W	15.74%	31.13%	38.95%	42.34%	57.54%	37.14%
40% W	14.09%	24.59%	30.49%	34.69%	46.59%	30.09%
60% W	10.54%	19.79%	21.84%	25.76%	37.18%	23.02%
80% W	7.43%	11.88%	14.75%	16.47%	22.07%	14.52%
100% W	4.95%	5.77%	3.96%	4.87%	5.52%	5.02%
Total	10.55%	18.63%	22.00%	24.83%	33.78%	21.96%

Table 35 Average reduction of α of $H - SDN$ compared to $B2$ for processes in class *L30*, by % of readers and % of writers.

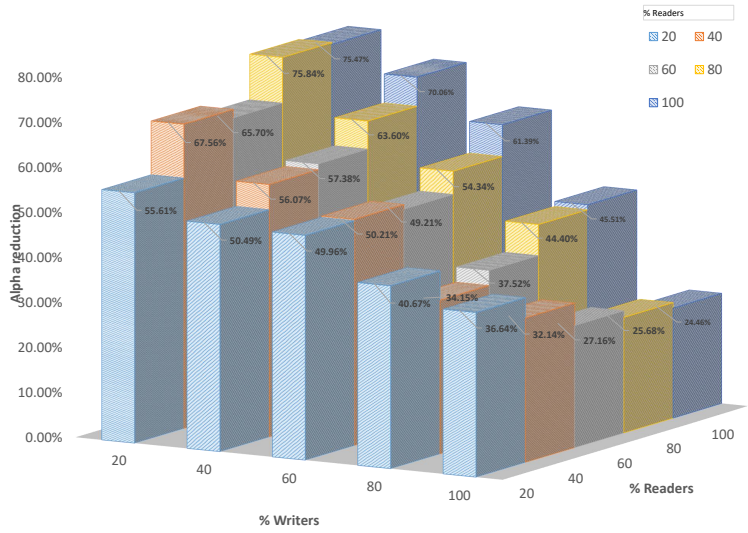


Fig. 5 Average values of α reduction from $B2$ to $H - SDN$ for the processes of class *M05*.

1.7 Influence of Safeness classes on α and β values

Fig. 8, 9, and 10 show the general trends of the α and β values over the process classes as the restriction level of the heuristic algorithm changes. We observe the increase in α as the number of allowed process partners for a transitive transmission increases, as well as the reduction of β which occurs at the same time.

1.8 Scalability

Our third evaluation goal, *EG3*, was aimed at assessing the scalability of our heuristic approach for inter-organizational processes. Each process model used in the evaluation can be a global process model in an inter-organizational setting, and each task in it might be a subprocess in the local process model. We therefore generated the bigger topologies of L class to evaluate the run-time behavior of the algorithm under more demanding conditions. We measured the execution times for the different algorithms over the processes in the data set to assess the temporal requirements for the computation.

The experiments required on average 15.39 milliseconds for executing $H - SDN$ over a given topology in the S class (with a maximum of 2.80 seconds), 191.82 milliseconds for a topology in the M class (with a maximum of 12.45 seconds), and 2608.15 milliseconds for a topology in the L class (with

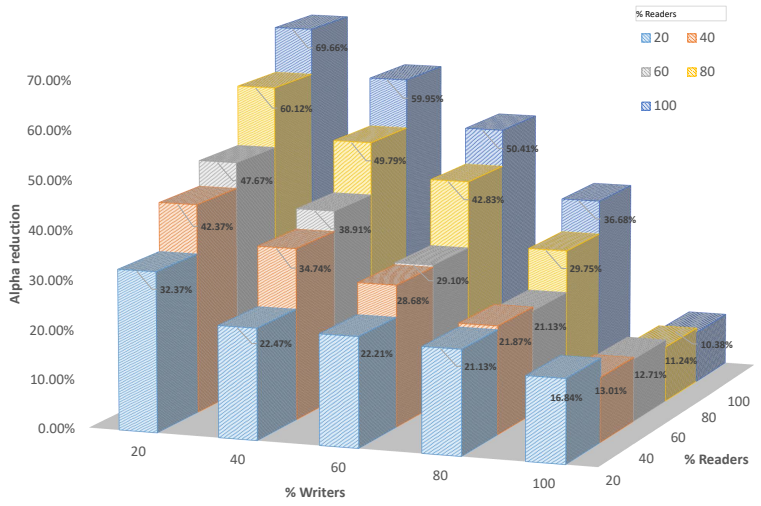


Fig. 6 Average values of α reduction from $B2$ to $H-SDN$ for the processes of class $M10$.

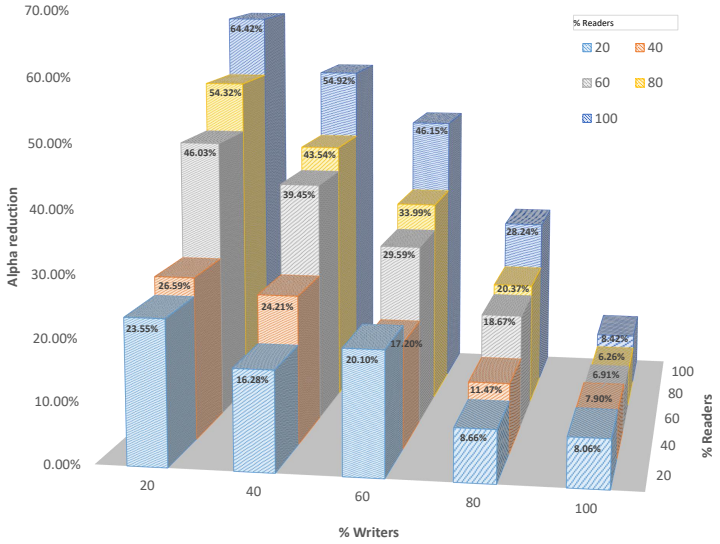


Fig. 7 Average values of α reduction from $B2$ to $H-SDN$ for the processes of class $M15$.

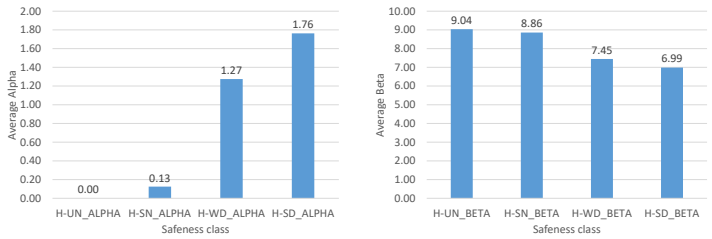


Fig. 8 Average values of α and β across the safeness classes for the processes of class *M05*.

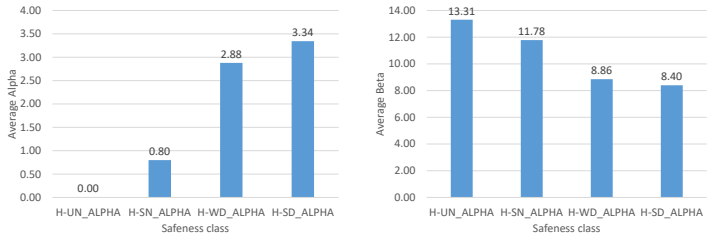


Fig. 9 Average values of α and β across the safeness classes for the processes of class *M10*.

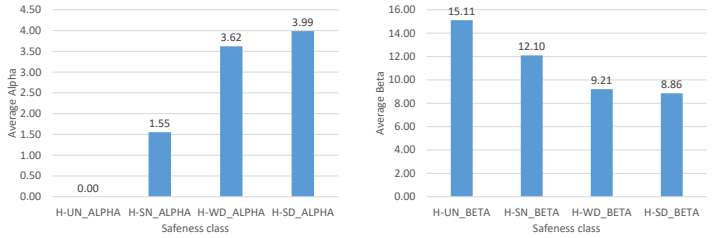


Fig. 10 Average values of α and β across the safeness classes for the processes of class *M15*.

Algorithm	Avg time [ms]	Max time [ms]
H-UN	15.54	3000.00
H-SN	15.13	3031.00
H-WDN	18.18	11717.00
H-SDN	15.39	2797.00

Table 36 Average and maximum execution times for the the different safeness classes of the heuristic algorithm over processes of class *S*.

a maximum of 462.31 seconds). Tables 36, 37, and 38 report the average and maximum times for the executions of the different restrictions of the heuristic algorithm over classes *S*, *M*, and *L*. Tables 39 to 47 report the average and maximum times of execution per each subclass.

Algorithm	Avg time [ms]	Max time [ms]
H-UN	98.97	5609.00
H-SN	92.55	5203.00
H-WDN	148.48	9781.00
H-SDN	191.82	12453.00

Table 37 Average and maximum execution times for the the different safeness classes of the heuristic algorithm over processes of class *M*.

Algorithm	Avg time [ms]	Max time [ms]
H-UN	700.21	212219.00
H-SN	656.41	97266.00
H-WDN	1922.45	270797.00
H-SDN	2608.15	462314.00

Table 38 Average and maximum execution times for the the different safeness classes of the heuristic algorithm over processes of class *L*.

Algorithm	Avg time [ms]	Max time [ms]
H-UN	15.15	47.00
H-SN	16.61	2875.00
H-WDN	19.33	3047.00
H-SDN	17.28	2797.00

Table 39 Average and maximum execution times for the the different safeness classes of the heuristic algorithm over processes of class *S02*.

Algorithm	Avg time [ms]	Max time [ms]
H-UN	21.59	3000.00
H-SN	19.90	3031.00
H-WDN	21.35	94.00
H-SDN	19.94	63.00

Table 40 Average and maximum execution times for the the different safeness classes of the heuristic algorithm over processes of class *S03*.

Algorithm	Avg time [ms]	Max time [ms]
H-UN	9.88	1127.00
H-SN	8.88	386.00
H-WDN	13.88	11717.00
H-SDN	8.97	330.00

Table 41 Average and maximum execution times for the the different safeness classes of the heuristic algorithm over processes of class *S04*.

Algorithm	Avg time [ms]	Max time [ms]
H-UN	81.79	2766.00
H-SN	83.46	4672.00
H-WDN	112.18	3016.00
H-SDN	110.11	5703.00

Table 42 Average and maximum execution times for the the different safeness classes of the heuristic algorithm over processes of class *M05*.

Algorithm	Avg time [ms]	Max time [ms]
H-UN	113.14	5609.00
H-SN	99.58	5203.00
H-WDN	164.69	9781.00
H-SDN	229.47	12453.00

Table 43 Average and maximum execution times for the the different safeness classes of the heuristic algorithm over processes of class *M10*.

Algorithm	Avg time [ms]	Max time [ms]
H-UN	101.99	5454.00
H-SN	94.61	5156.00
H-WDN	168.56	9093.00
H-SDN	235.88	12359.00

Table 44 Average and maximum execution times for the the different safeness classes of the heuristic algorithm over processes of class *M15*.

Algorithm	Avg time [ms]	Max time [ms]
H-UN	616.84	28828.00
H-SN	601.79	36203.00
H-WDN	1253.86	114922.00
H-SDN	1737.71	132656.00

Table 45 Average and maximum execution times for the the different safeness classes of the heuristic algorithm over processes of class *L10*.

Algorithm	Avg time [ms]	Max time [ms]
H-UN	778.26	21515.00
H-SN	759.51	29422.00
H-WDN	3157.00	270797.00
H-SDN	4646.46	462314.00

Table 46 Average and maximum execution times for the the different safeness classes of the heuristic algorithm over processes of class *L20*.

Algorithm	**Avg time [ms]**	**Max time [ms]**
H-UN	705.53	212219.00
H-SN	607.94	97266.00
H-WDN	1356.50	196641.00
H-SDN	1440.28	86688.00

Table 47 Average and maximum execution times for the the different safeness classes of the heuristic algorithm over processes of class *L30*.