

ISM model

April 5, 2019

	12	11	10	9	8	7	6	5	4	3	2	1
parameters												
1	V	V	V	V	V	V	V	V	V	V	V	NaN
2	A	A	A	0	A	A	0	A	A	A	NaN	NaN
3	V	V	V	V	V	0	V	A	X	NaN	NaN	NaN
4	X	V	V	V	V	V	0	A	NaN	NaN	NaN	NaN
5	V	V	V	V	V	V	V	NaN	NaN	NaN	NaN	NaN
6	0	V	A	V	A	0	NaN	NaN	NaN	NaN	NaN	NaN
7	A	V	A	0	A	NaN	NaN	NaN	NaN	NaN	NaN	NaN
8	A	V	V	V	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
9	0	A	A	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
10	A	V	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
11	A	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
12	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

0.1 name

Out[44]: Int64Index([1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12], dtype='int64', name='parameters')

0.2 Initial Reachability Matrix

Out[32]: array([[1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1],
[0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 1, 1, 1, 0, 1, 0, 1, 1, 1, 1, 1],
[0, 1, 1, 1, 0, 0, 1, 1, 1, 1, 1, 1],
[0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1],
[0, 0, 0, 0, 0, 1, 0, 0, 1, 0, 1, 0],
[0, 1, 0, 0, 0, 0, 1, 0, 0, 0, 1, 0],
[0, 1, 0, 0, 0, 1, 1, 1, 1, 1, 1, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0],
[0, 1, 0, 0, 0, 1, 1, 0, 1, 1, 1, 0],
[0, 1, 0, 0, 0, 0, 0, 0, 1, 0, 1, 0],
[0, 1, 0, 1, 0, 0, 1, 1, 0, 1, 1, 1]])

0.3 Final Reachability Matrix

Final Reachability matrix

```
Out[34]:
```

	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	1	1	1	1	1	1	1	1	1
2	0	1	0	0	0	0	0	0	0	0	0	0
3	0	1	1	1	0	1	1	1	1	1	1	1
4	0	1	1	1	0	1	1	1	1	1	1	1
5	0	1	1	1	1	1	1	1	1	1	1	1
6	0	1	0	0	0	1	0	0	1	0	1	0
7	0	1	0	0	0	0	1	0	1	0	1	0
8	0	1	0	0	0	1	1	1	1	1	1	0
9	0	0	0	0	0	0	0	0	1	0	0	0
10	0	1	0	0	0	1	1	0	1	1	1	0
11	0	1	0	0	0	0	0	0	1	0	1	0
12	0	1	1	1	0	1	1	1	1	1	1	1

```
Out[52]:
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	Parameter	Reachability_set	Level \
0	1.0	{1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12}	NaN
1	2.0	{2}	NaN
2	3.0	{2, 3, 4, 6, 7, 8, 9, 10, 11, 12}	NaN
3	4.0	{2, 3, 4, 6, 7, 8, 9, 10, 11, 12}	NaN
4	5.0	{2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12}	NaN
5	6.0	{9, 2, 11, 6}	NaN
6	7.0	{9, 2, 11, 7}	NaN
7	8.0	{2, 6, 7, 8, 9, 10, 11}	NaN
8	9.0	{9}	NaN
9	10.0	{2, 6, 7, 9, 10, 11}	NaN
10	11.0	{9, 2, 11}	NaN
11	12.0	{2, 3, 4, 6, 7, 8, 9, 10, 11, 12}	NaN

	Antecedent_set	Intersection_set
0	{1}	{1}
1	{1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12}	{2}
2	{1, 3, 4, 5, 12}	{3, 4, 12}
3	{1, 3, 4, 5, 12}	{3, 4, 12}
4	{1, 5}	{5}
5	{1, 3, 4, 5, 6, 8, 10, 12}	{6}
6	{1, 3, 4, 5, 7, 8, 10, 12}	{7}
7	{1, 3, 4, 5, 8, 12}	{8}
8	{1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12}	{9}
9	{1, 3, 4, 5, 8, 10, 12}	{10}
10	{1, 3, 4, 5, 6, 7, 8, 10, 11, 12}	{11}
11	{1, 3, 4, 5, 12}	{3, 4, 12}

1 Barrier Level Iteration:

Iteration Number: 1

	Parameter	Reachability_set	Level \
0	1.0	{1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12}	NaN
1	2.0	{2}	1.0
2	3.0	{2, 3, 4, 6, 7, 8, 9, 10, 11, 12}	NaN
3	4.0	{2, 3, 4, 6, 7, 8, 9, 10, 11, 12}	NaN
4	5.0	{2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12}	NaN
5	6.0	{9, 2, 11, 6}	NaN
6	7.0	{9, 2, 11, 7}	NaN
7	8.0	{2, 6, 7, 8, 9, 10, 11}	NaN
8	9.0	{9}	1.0
9	10.0	{2, 6, 7, 9, 10, 11}	NaN
10	11.0	{9, 2, 11}	NaN
11	12.0	{2, 3, 4, 6, 7, 8, 9, 10, 11, 12}	NaN

	Antecedent_set	Intersection_set
0	{1}	{1}
1	{1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12}	{2}
2	{1, 3, 4, 5, 12}	{3, 4, 12}
3	{1, 3, 4, 5, 12}	{3, 4, 12}
4	{1, 5}	{5}
5	{1, 3, 4, 5, 6, 8, 10, 12}	{6}
6	{1, 3, 4, 5, 7, 8, 10, 12}	{7}
7	{1, 3, 4, 5, 8, 12}	{8}
8	{1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12}	{9}
9	{1, 3, 4, 5, 8, 10, 12}	{10}
10	{1, 3, 4, 5, 6, 7, 8, 10, 11, 12}	{11}
11	{1, 3, 4, 5, 12}	{3, 4, 12}

Iteration Number: 2

	Parameter	Reachability_set	Level \
0	1.0	{1, 3, 4, 5, 6, 7, 8, 10, 11, 12}	NaN
2	3.0	{3, 4, 6, 7, 8, 10, 11, 12}	NaN
3	4.0	{3, 4, 6, 7, 8, 10, 11, 12}	NaN
4	5.0	{3, 4, 5, 6, 7, 8, 10, 11, 12}	NaN
5	6.0	{11, 6}	NaN
6	7.0	{11, 7}	NaN
7	8.0	{6, 7, 8, 10, 11}	NaN
9	10.0	{10, 11, 6, 7}	NaN
10	11.0	{11}	2.0
11	12.0	{3, 4, 6, 7, 8, 10, 11, 12}	NaN

	Antecedent_set	Intersection_set
0	{1}	{1}

2	{1, 3, 4, 5, 12}	{3, 4, 12}
3	{1, 3, 4, 5, 12}	{3, 4, 12}
4	{1, 5}	{5}
5	{1, 3, 4, 5, 6, 8, 10, 12}	{6}
6	{1, 3, 4, 5, 7, 8, 10, 12}	{7}
7	{1, 3, 4, 5, 8, 12}	{8}
9	{1, 3, 4, 5, 8, 10, 12}	{10}
10	{1, 3, 4, 5, 6, 7, 8, 10, 11, 12}	{11}
11	{1, 3, 4, 5, 12}	{3, 4, 12}

Iteration Number: 3

	Parameter	Reachability_set	Level \
0	1.0	{1, 3, 4, 5, 6, 7, 8, 10, 12}	NaN
2	3.0	{3, 4, 6, 7, 8, 10, 12}	NaN
3	4.0	{3, 4, 6, 7, 8, 10, 12}	NaN
4	5.0	{3, 4, 5, 6, 7, 8, 10, 12}	NaN
5	6.0	{6}	3.0
6	7.0	{7}	3.0
7	8.0	{8, 10, 6, 7}	NaN
9	10.0	{10, 6, 7}	NaN
11	12.0	{3, 4, 6, 7, 8, 10, 12}	NaN

	Antecedent_set	Intersection_set
0	{1}	{1}
2	{1, 3, 4, 5, 12}	{3, 4, 12}
3	{1, 3, 4, 5, 12}	{3, 4, 12}
4	{1, 5}	{5}
5	{1, 3, 4, 5, 6, 8, 10, 12}	{6}
6	{1, 3, 4, 5, 7, 8, 10, 12}	{7}
7	{1, 3, 4, 5, 8, 12}	{8}
9	{1, 3, 4, 5, 8, 10, 12}	{10}
11	{1, 3, 4, 5, 12}	{3, 4, 12}

Iteration Number: 4

	Parameter	Reachability_set	Level	Antecedent_set \
0	1.0	{1, 3, 4, 5, 8, 10, 12}	NaN	{1}
2	3.0	{3, 4, 8, 10, 12}	NaN	{1, 3, 4, 5, 12}
3	4.0	{3, 4, 8, 10, 12}	NaN	{1, 3, 4, 5, 12}
4	5.0	{3, 4, 5, 8, 10, 12}	NaN	{1, 5}
7	8.0	{8, 10}	NaN	{1, 3, 4, 5, 8, 12}
9	10.0	{10}	4.0	{1, 3, 4, 5, 8, 10, 12}
11	12.0	{3, 4, 8, 10, 12}	NaN	{1, 3, 4, 5, 12}

	Intersection_set
0	{1}

```

2      {3, 4, 12}
3      {3, 4, 12}
4          {5}
7          {8}
9          {10}
11     {3, 4, 12}

```

Iteration Number: 5

	Parameter	Reachability_set	Level	Antecedent_set \
0	1.0	{1, 3, 4, 5, 8, 12}	NaN	{1}
2	3.0	{8, 3, 4, 12}	NaN	{1, 3, 4, 5, 12}
3	4.0	{8, 3, 4, 12}	NaN	{1, 3, 4, 5, 12}
4	5.0	{3, 4, 5, 8, 12}	NaN	{1, 5}
7	8.0	{8}	5.0	{1, 3, 4, 5, 8, 12}
11	12.0	{8, 3, 4, 12}	NaN	{1, 3, 4, 5, 12}

```

Intersection_set
0      {1}
2      {3, 4, 12}
3      {3, 4, 12}
4          {5}
7          {8}
11     {3, 4, 12}

```

Iteration Number: 6

	Parameter	Reachability_set	Level	Antecedent_set	Intersection_set
0	1.0	{1, 3, 4, 5, 12}	NaN	{1}	{1}
2	3.0	{3, 4, 12}	6.0	{1, 3, 4, 5, 12}	{3, 4, 12}
3	4.0	{3, 4, 12}	6.0	{1, 3, 4, 5, 12}	{3, 4, 12}
4	5.0	{12, 3, 4, 5}	NaN	{1, 5}	{5}
11	12.0	{3, 4, 12}	6.0	{1, 3, 4, 5, 12}	{3, 4, 12}

Iteration Number: 7

	Parameter	Reachability_set	Level	Antecedent_set	Intersection_set
0	1.0	{1, 5}	NaN	{1}	{1}
4	5.0	{5}	7.0	{1, 5}	{5}

Iteration Number: 8

	Parameter	Reachability_set	Level	Antecedent_set	Intersection_set
0	1.0	{1}	8.0	{1}	{1}

Final Barrier Level Iteration

	Parameter	Reachability_set	Antecedent_set \
1	2.0	{2}	{1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12}
8	9.0	{9}	{1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12}
10	11.0	{11}	{1, 3, 4, 5, 6, 7, 8, 10, 11, 12}
5	6.0	{6}	{1, 3, 4, 5, 6, 8, 10, 12}
6	7.0	{7}	{1, 3, 4, 5, 7, 8, 10, 12}
9	10.0	{10}	{1, 3, 4, 5, 8, 10, 12}
7	8.0	{8}	{1, 3, 4, 5, 8, 12}
2	3.0	{3, 4, 12}	{1, 3, 4, 5, 12}
3	4.0	{3, 4, 12}	{1, 3, 4, 5, 12}
11	12.0	{3, 4, 12}	{1, 3, 4, 5, 12}
4	5.0	{5}	{1, 5}
0	1.0	{1}	{1}

	Intersection_set	Level
1	{2}	1.0
8	{9}	1.0
10	{11}	2.0
5	{6}	3.0
6	{7}	3.0
9	{10}	4.0
7	{8}	5.0
2	{3, 4, 12}	6.0
3	{3, 4, 12}	6.0
11	{3, 4, 12}	6.0
4	{5}	7.0
0	{1}	8.0

```
Out[60]:
```

	2	9	11	6	7	10	8	3	4	12	5	1
2	1	0	0	0	0	0	0	0	0	0	0	0
9	0	1	0	0	0	0	0	0	0	0	0	0
11	1	1	1	0	0	0	0	0	0	0	0	0
6	1	1	1	1	0	0	0	0	0	0	0	0
7	1	1	1	0	1	0	0	0	0	0	0	0
10	1	1	1	1	1	1	0	0	0	0	0	0
8	1	1	1	1	1	1	1	0	0	0	0	0
3	1	1	1	1	1	1	1	1	1	1	0	0
4	1	1	1	1	1	1	1	1	1	1	0	0
12	1	1	1	1	1	1	1	1	1	1	0	0
5	1	1	1	1	1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1	1	1	1	1	1

<https://pypi.org/project/pydot/> <http://graphviz.org/> <http://pygraphviz.github.io/documentation/pygraphviz-1.5/tutorial.html#graphs>

```
Out[46]: '2'
```

'ISM.gv.pdf'

last step : add driving power at the last to FRM