The Quality of Approximation Algorithms implemented in the Flow Line Planning Software FlowEval – Numerical Results

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Abstract

In this report we provide numerical results with respect to the approximation quality of the algorithms implemented in the software system **FlowEval**. Most of the systems considered are real-life systems. Not only linear but also assembly structures are considered. The computed values are compared to simulation results generated with the simulation software *Arena*®. The results show that the performance of the systems is predicted very well.

1 Introduction

In industrial factory planning practice, the evaluation of the performance of a planned production system is a prerequisite for an economically sound investment decision. In many companies planners use simulation models to approximate the performance of a planned flow production system. Although simulation models are very useful in the detailed planning phase of a production system, the costs of a simulation study in terms of development effort and the time to perform a statistically significant number of simulation runs usually are very high. This is particularly true in cases, when the planner seeks the optimum system configuration and consequently a large number of simulation runs have to be carried out.

Closely connected with recently emerging „Digital Factory" projects, an increasing number of companies now consider the application of analytical tools to predict the performance of a considered flow production system, which is in sharp contrast to the crude rule-of-thumb-planning practice based on experience of the past.

In the following the quality of the approximations provided by the performance evaluation algorithms implemented in the software system **FlowEval** is tested with the help of a number of invented and real-life data sets. As a detailed discussion of the type of system that may be evaluated with the help of available analytical algorithms and references are provided in Tempelmeier (2003), we confine our attention to the description of the systems considered and the experimental results. Basically this report can be considered as a supplement to the Tempelmeier (2003) paper. Further background with respect to the principle structure of the approximation methods applied is provided by Dallery and Gershwin (1992), Buzacott and Shanthikumar (1993), Gershwin (1994) and the literature cited therein.

The real-life data sets considered were slightly modified in order to hide their origin. For each system we provide a comprehensive characterisation in terms of the station parameters. The simulation software used was *Arena*®. The simulation models (including animation objects) were automatically constructed with a model generator that is available as an optional module of **FlowEval**. The *Arena* templates required are the

Basic Process Template and the *Advanced Process Template*. Both the model logic as well as the animation structure of the generated *Arena* simulation model are available to the user for further changes – if required. The *Arena* modules used for a linear flow production system consisting of four stations and the associated animation view are shown in figures 1 and 2.

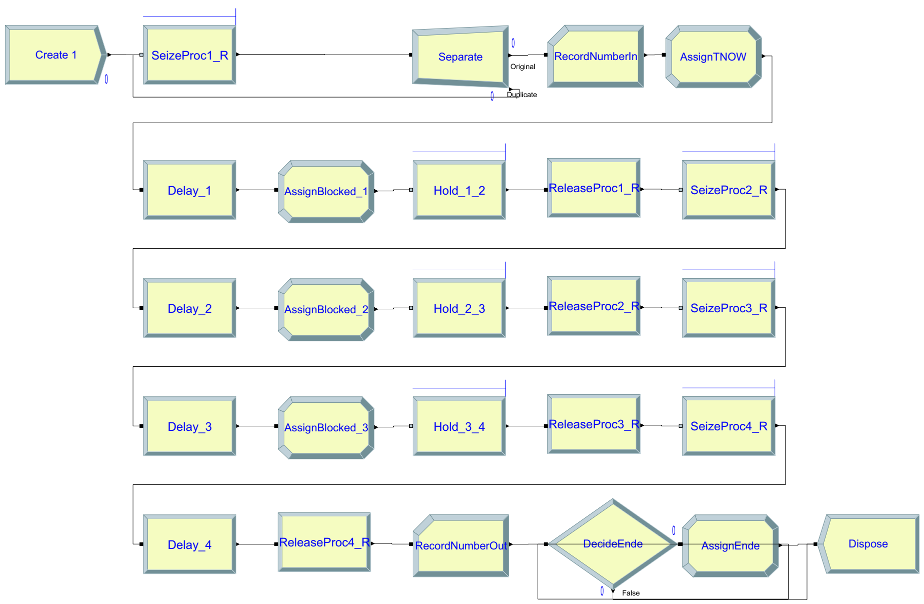

Figure 1: Model logic for a linear flow production system

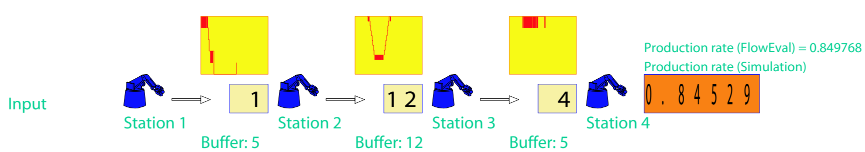

Figure 2: Animation view for a linear flow production system

For systems with converging material flow the model logic of the simulation model is significantly more complicated. Figure 2 shows the animation view of an assembly system.

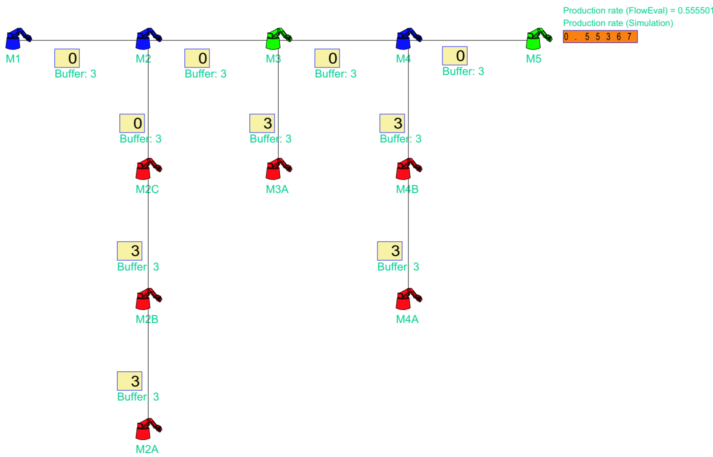

Figure 3: Animation view for a flow production system with converging material flow

2 Numerical results

The systems considered differ with respect to the following system characteristics.

- Structure: linear (L), assembly (A)
- Processing times: deterministic (D), stochastic (S)
- Source of data: invented (I), real-life (R)
- Degree of homogenity of stations
  - Workload per station: (avg, min, max, for stochastic processing times: CV = coefficient of variation)
  - Availabilities (avg, min, max)
  - Mean time-to-repair (avg, min, max)

The systems are labeled with the triple (Structure/Processing times/System origin). For example, (L/S/I) means a linear system with stochastic processing times and invented data. The results presented are the system production rates as a function of the buffer sizes. In cases where only a single number for the buffer sizes is given, this buffer size applies to all buffers (stations). For each system configuration considered, ten independent simulation runs were performed with a production quantity of 50000 units each. In the simulations, the repair times as well as the lifetimes were assumed to be exponentially distributed. For the systems with stochastic processing times the processing time distributions were assumed to be gamma distributions with the given coefficient of variation (CV).

2.1 Linear systems

2.1.1 System 1: L/S/I

Number of Stations	10			
	avg	CV	min	max
Workloads	1	0.4	1	1
Availability	1.00	–	1.00	1.00
MTTR	–	–	–	–

Table 1: Data

	Buffer size per Station		
	1	3	5
computed	0.81215	0.914110	0.944890
simulated	0.83106	0.915573	0.943787
deviation	-2.28%	-0.16%	0.12%

Table 2: Results - Production rates

2.1.2 System 2: L/S/I

Number of Stations	16			
	avg	CV	min	max
Workloads	30	0.5	22	36
Availability	1.00	–	1.00	1.00
MTTR	–	–	–	–

Table 3: Data

	Buffer size per Station	
	6	optimal (total 90)
computed	0.027110	0.027500
simulated	0.026758	0.027016
deviation	1.32%	1.79%

Table 4: Results - Production rates

2.1.3 System 3: L/S/R

Number of Stations	10			
	avg	CV	min	max
Workloads	1.8	0.4	1.72	1.88
Availability	1.00	–	1.00	1.00
MTTR	–	–	–	–

Table 5: Data

	Buffer size per Station			
	1	2	3	optimal (total 83)
computed	0.413930	0.456000	0.477500	0.519960
simulated	0.425173	0.460647	0.479328	0.517820
deviation	-2.64%	-1.01%	-0.38%	0.41%

Table 6: Results - Production rates

2.1.4 System 4: L/D/I

Number of Stations	80			
	avg	CV	min	max
Workloads	232	–	214	246
Availability	0.88	–	0.80	0.96
MTTR	300	–	300	300

Table 7: Data

	Buffer size per Station	
	2	optimal (total 334)
computed	0.003080	0.003190
simulated	0.002951	0.003114
deviation	4.37%	2.40%

Table 8: Results - Production rates

2.1.5 System 5: L/D/R

Number of Stations	14			
	avg	CV	min	max
Workloads	1.04	–	0.85	1.23
Availability	0.92	–	0.92	0.98
MTTR	7.27	–	4.5	12

Table 9: Data

	Buffer size per Station		
	2	5	optimal (total 63)
computed	0.694110	0.738840	0.770000
simulated	0.697719	0.734716	0.762362
deviation	-0.52%	0.56%	1.00%

Table 10: Results - Production rates

2.1.6 System 6: L/D/R

Number of Stations	6			
	avg	CV	min	max
Workloads	30	–	30	30
Availability	0.94	–	0.91	0.95
MTTR	690	–	610	820

Table 11: Data

	Buffer size per Station		
	0	3	optimal (total 26)
computed	0.024240	0.025120	0.028000
simulated	0.024289	0.025140	0.027767
deviation	-0.20%	-0.08%	0.84%

Table 12: Results - Production rates

2.1.7 System 7: L/D/R

Number of Stations	10			
	avg	CV	min	max
Workloads	12	–	11	17
Availability	0.99	–	0.99	0.99
MTTR	20	–	20	20

Table 13: Data

	Buffer size per Station		
	1	3	optimal (total 26)
computed	0.057410	0.057550	0.05762
simulated	0.057433	0.057763	0.05763
deviation	-0.04%	-0.02%	-0.02%

Table 14: Results - Production rates

2.1.8 System 8: L/D/R

Number of Stations	8			
	avg	CV	min	max
Workloads	232	–	214	246
Availability	0.88	–	0.80	0.96
MTTR	300	–	300	300

Table 15: Data

	Buffer size per Station				
	1	2	3	optimal (total 21)	optimal (total 54)
computed	0.002873	0.003170	0.003320	0.003350	0.003580
simulated	0.002940	0.003169	0.003300	0.003329	0.003563
deviation	-2.28%	0.03%	0.61%	0.63%	0.48%

Table 16: Results - Production rates

2.1.9 System 9: L/D/R

Number of Stations	23			
	avg	CV	min	max
Workloads	4.9	–	4.1	6.1
Availability	0.96	–	0.82	1.00
MTTR	68	–	27	230

Table 17: Data

	Buffer size per Station	
	5	optimal (total 110)
computed	0.122940	0.132020
simulated	0.123142	0.130210
deviation	-0.16%	1.39%

Table 18: Results - Production rates

Note: In this real-life system the optimal distribution of 110 buffers has a production rate that is 5.7% larger then the even distribution of the same number of buffers.

2.1.10 System 10: L/D/R

Number of Stations	21			
	avg	CV	min	max
Workloads	0.99	0	0.9	1.05
Availability	0.88	0	0.85	0.89
MTTR	30	0	30	30

Table 19: Data

Note: This system has very long failure times (MTTR) relative to the processing times, which were considered by the planners to test the approximation in a worst-case scenario.

	Buffer size per Station	
	5	optimal (total 102)
computed	0.423460	0.444080
simulated	0.422471	0.433951
deviation	0.23%	2.33%

Table 20: Results - Production rates

2.2 Assembly systems

2.2.1 System 11: A/D/I

Number of Stations	6			
	avg	CV	min	max
Workloads	10	–	10	10
Availability	0.9091	–	0.9091	0.9091
MTTR	10	–	10	10

Table 21: Data

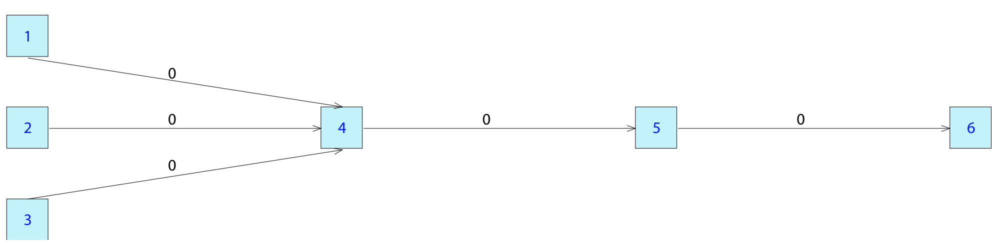

Figure 4: Layout

	Buffer size per Station			
	0	1	2	optimal (total 20)
computed	0.062502	0.075868	0.080889	0.08491
simulated	0.067876	0.076962	0.081208	0.08482
deviation	-7.92%	-1.42%	-0.39%	-0.10%

Table 22: Results - Production rates

2.2.2 System 12: A/D/I

Number of Stations	12			
	avg	CV	min	max
Workloads	300	–	300	300
Availability	0.95	–	0.95	0.95
MTTR	300	–	300	300

Table 23: Data

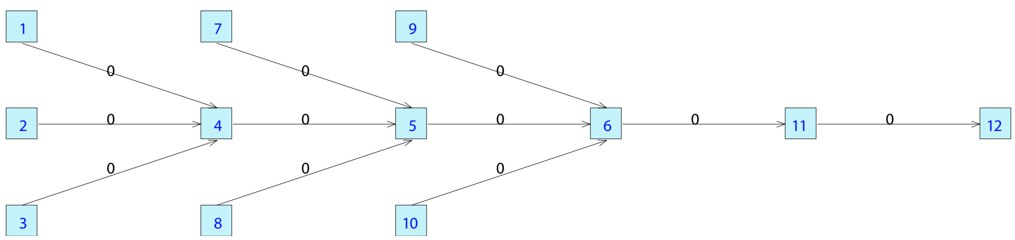

Figure 5: Layout

	Buffer size per Station			
	0	1	2	optimal (total 55)
computed	0.012255	0.013343	0.014165	0.016000
simulated	0.012634	0.013550	0.014353	0.015961
deviation	-3.00%	-1.53%	-1.31%	0.24%

Table 24: Results - Production rates

2.2.3 System 13: A/D/I

Number of Stations	6			
	avg	CV	min	max
Workloads	10	–	10	10
Availability	0.9091	–	0.9091	0.9091
MTTR	10	–	10	10

Table 25: Data

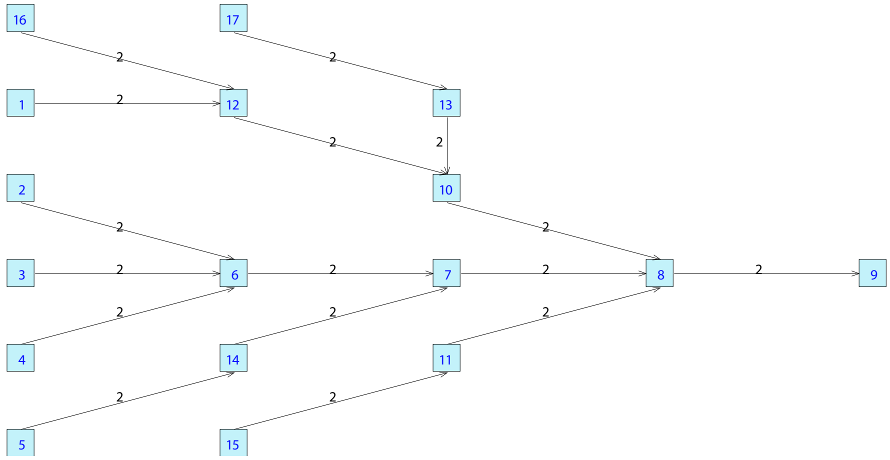

Figure 6: Layout

	Buffer size per Station		
	1	2	optimal (total 64)
computed	0.067589	0.076587	0.083400
simulated	0.070478	0.076921	0.082855
deviation	-4.09%	-0.43%	0.66%

Table 26: Results - Production rates

2.2.4 System 14: A/D/I

Number of Stations	11			
	avg	CV	min	max
Workloads	1	–	1	1
Availability	0.90	–	0.90	0.90
MTTR	1	–	1	1

Table 27: Data

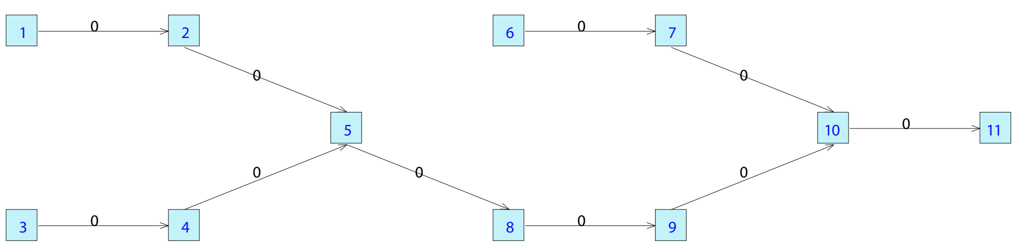

Figure 7: Layout

	Buffer size per Station			
	0	1	2	optimal (total 25)
computed	0.4500	0.704640	0.776563	0.79610
simulated	0.5927	0.719928	0.775467	0.79143
deviation	-24.07%	-2.12%	0.14%	0.59%

Table 28: Results - Production rates

2.2.5 System 15: A/D/R

Number of Stations	14			
	avg	CV	min	max
Workloads	229	–	206	248
Availability	0.89	–	0.80	0.96
MTTR	300	–	300	300

Table 29: Data

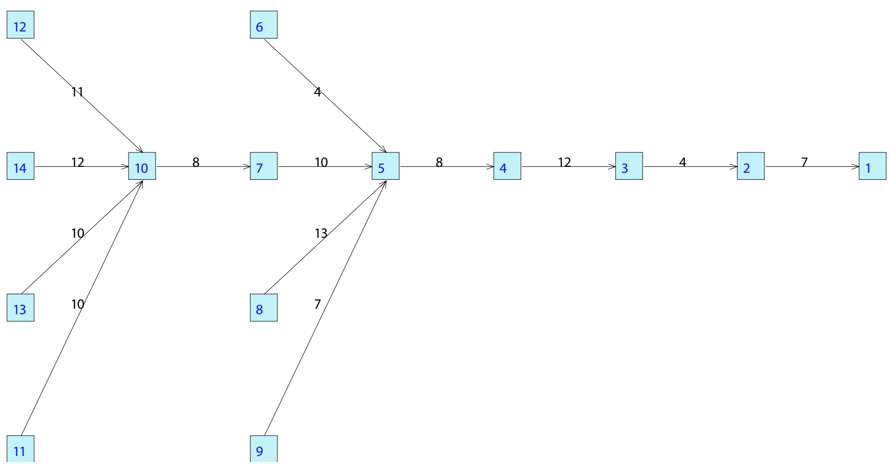

Figure 8: Layout

	Buffer size per Station			
	1	optimal (total 14)	optimal (total 23)	optimal (total 116)
computed	0.002529	0.002703	0.003000	0.003592
simulated	0.002755	0.002821	0.003027	0.003578
deviation	-8.94%	-4.36%	-0.89%	0.39%

Table 30: Results - Production rates

2.2.6 System 16: A/D/I

This is an extension of the above system with several stations added. The added stations have the same characteristics as the stations of the original system.

Number of Stations	27			
	avg	CV	min	max
Workloads	229	–	206	248
Availability	0.89	–	0.80	0.96
MTTR	300	–	300	300

Table 31: Data

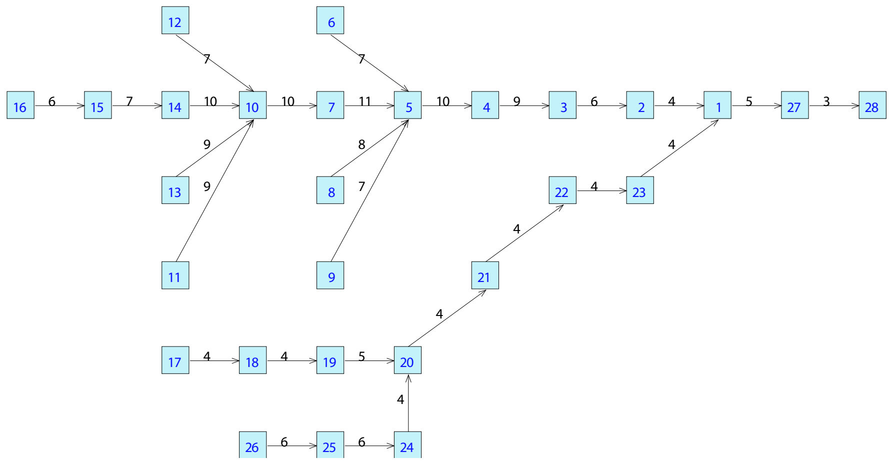

Figure 9: Layout

The buffer sizes were optimized with respect to a target production rate of 0.00360.

	Buffer size
	optimal (total 174)
computed	0.003600
simulated	0.003533
deviation	1.90%

Table 32: Results - Production rates

2.2.7 System 17: A/D/R

Number of Stations	30			
	avg	CV	min	max
Workloads	482	–	449	519
Availability	0.97	–	0.935	0.999
MTTR	300	–	300	300

Table 33: Data

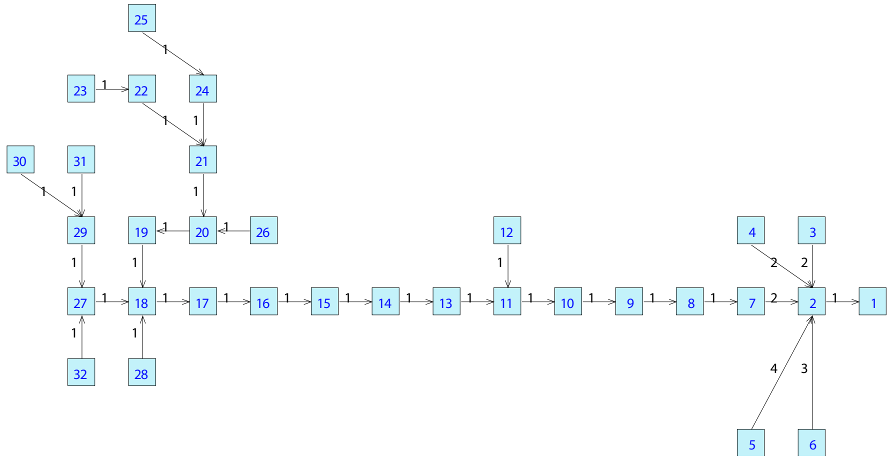

Figure 10: Layout

	Buffer size per Station		
	1	optimal (total 39)	optimal (total 63)
computed	0.001731	0.001800	0.001830
simulated	0.001737	0.001794	0.001817
deviation	-0.34%	0.33%	0.72%

Table 34: Results - Production rates

2.2.8 System 18: A/D/R

Number of Stations	11			
	avg	CV	min	max
Workloads	45	–	43	47
Availability	0.90	–	0.90	0.90
MTTR	250	–	250	250

Table 35: Data

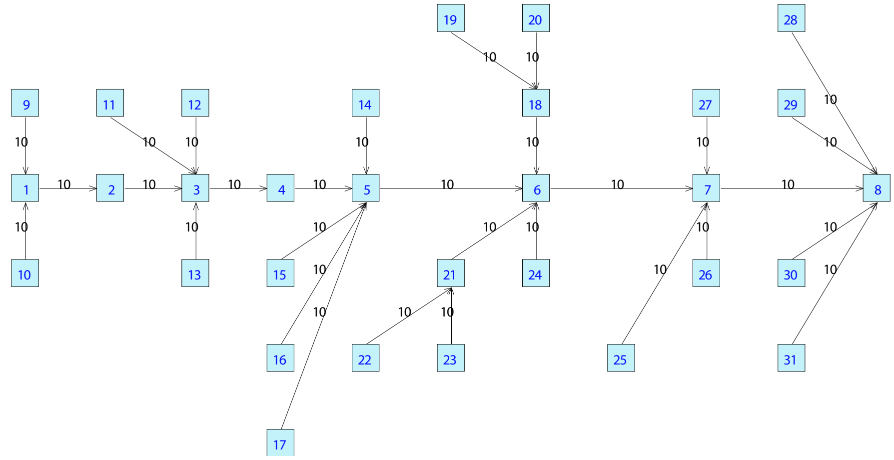

Figure 11: Layout

	Buffer size per Station			
	3	5	10	optimal (total 421)
computed	0.010928	0.012891	0.015529	0.017000
simulated	0.011435	0.013039	0.015361	0.016636
deviation	-4.43	-1.14%	1.09%	2.19%

Table 36: Results - Production rates

2.2.9 System 19: A/D/R

Number of Stations	21			
	avg	CV	min	max
Workloads	0.82	–	0.71	51
Availability	0.96	–	0.90	0.999
MTTR	16.9	–	11.9	20

Table 37: Data

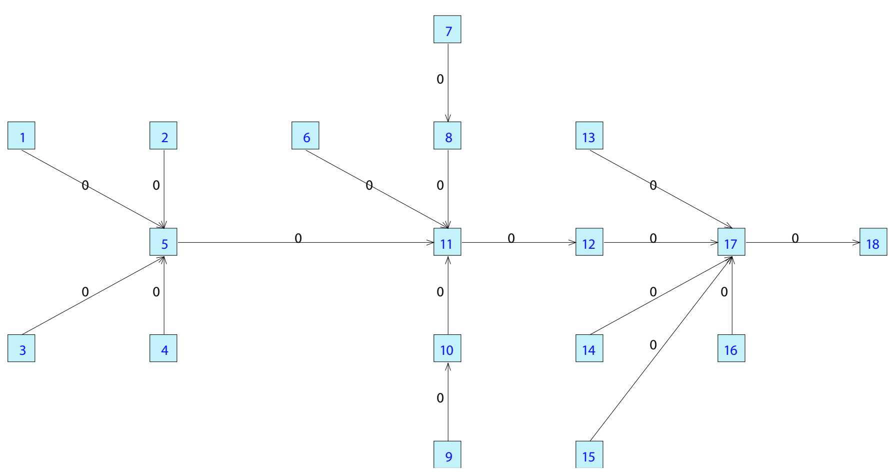

Figure 12: Layout

	Buffer size per Station			
	1	2	optimal (total 35)	optimal(total 86)
computed	0.749417	0.767767	0.799740	0.860040
simulated	0.754146	0.773514	0.803707	0.863138
deviation	-0.63%	-0.74%	-0.49%	-0.36%

Table 38: Results - Production rates

2.2.10 System 20: A/D/R

Number of Stations	10			
	avg	CV	min	max
Workloads	50	–	49	51
Availability	0.97	–	0.96	0.99
MTTR	450	–	450	450

Table 39: Data

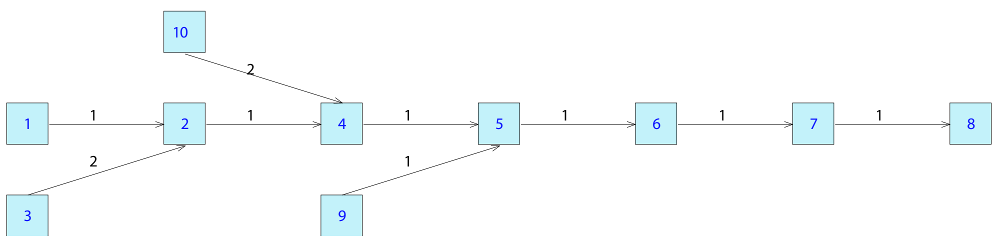

Figure 13: Layout

	Buffer size per Station		
	1	2	3
computed	0.015946	0.016319	0.016627
simulated	0.015999	0.016339	0.016601
deviation	-0.33%	-0.12%	0.16%

Table 40: Results - Production rates

2.2.11 System 21: A/D/R

Number of Stations	13			
	avg	CV	min	max
Workloads	135	–	135	135
Availability	0.96	–	0.93	0.99
MTTR	405	–	405	405

Table 41: Data

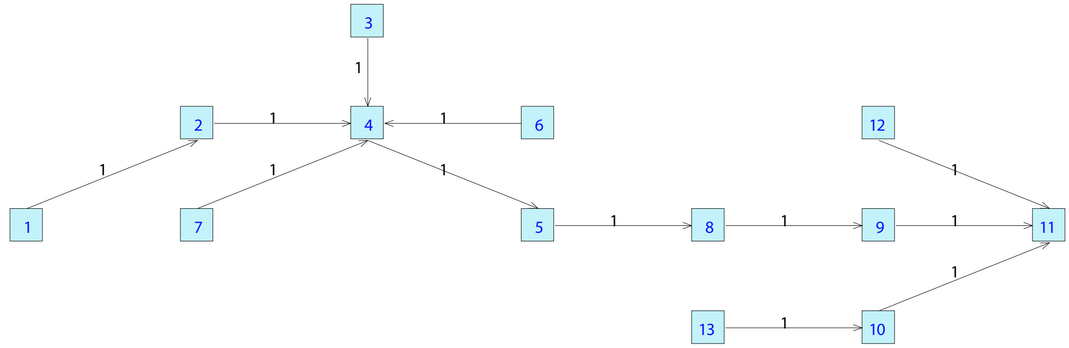

Figure 14: Layout

	Buffer size per Station		
	1	2	3
computed	0.005791	0.006163	0.006379
simulated	0.005851	0.006142	0.006333
deviation	-1.03%	0.34%	0.73%

Table 42: Results - Production rates

3 Conclusion

The numerical results presented show that the algorithms implemented in **FlowEval** are very precise for a wide variety of system designs. Significant deviations from the simulation results occur only in those cases where in despite of the stochastic characteristics of a system a planner would refuse to include even a minimum amount of buffering into the system. However, usually a planner will be aware of the necessity to include buffers and **FlowEval** will provide to him suggestions as to where the buffers are required. As **FlowEval** is based on a more or less abstract model of the considered flow production system, before the implementation of a proposed system configuration a detailed simulation should be carried out. To this end, **FlowEval** has been designed such that it can be applied as a performance evaluation and optimistion module in the frame of an overall planning concept.

References

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