A simulation and queueing model of the orthopaedic division at the Middelheim Hospital (Belgium): throughput time estimation through capacity and variability analysis

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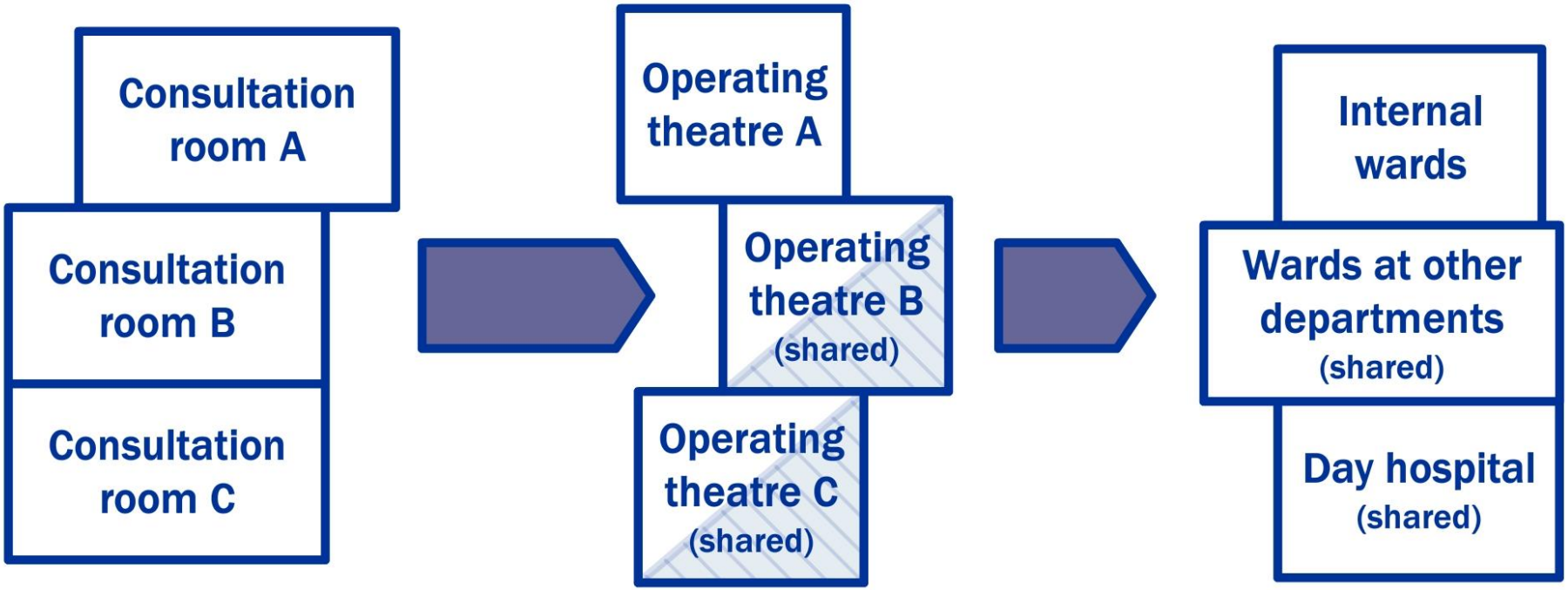
- ‘70s: Rampant health care expenditures reach their peak.
- Introduction of operations management techniques, resulting in the development of DRGs, clinical pathways, six sigma quality care programs, …
- The greater part of contributions stems from the last decades:
  - Fetter (1991): Founding father of the DRG-concept
  - Zander (1985): Clinical pathways
  - The start of numerous health care management journals (e.g. Health Care Management Science (º1998)).
- In Belgium, hospital reimbursement is based on flow time of patients belonging to one DRG

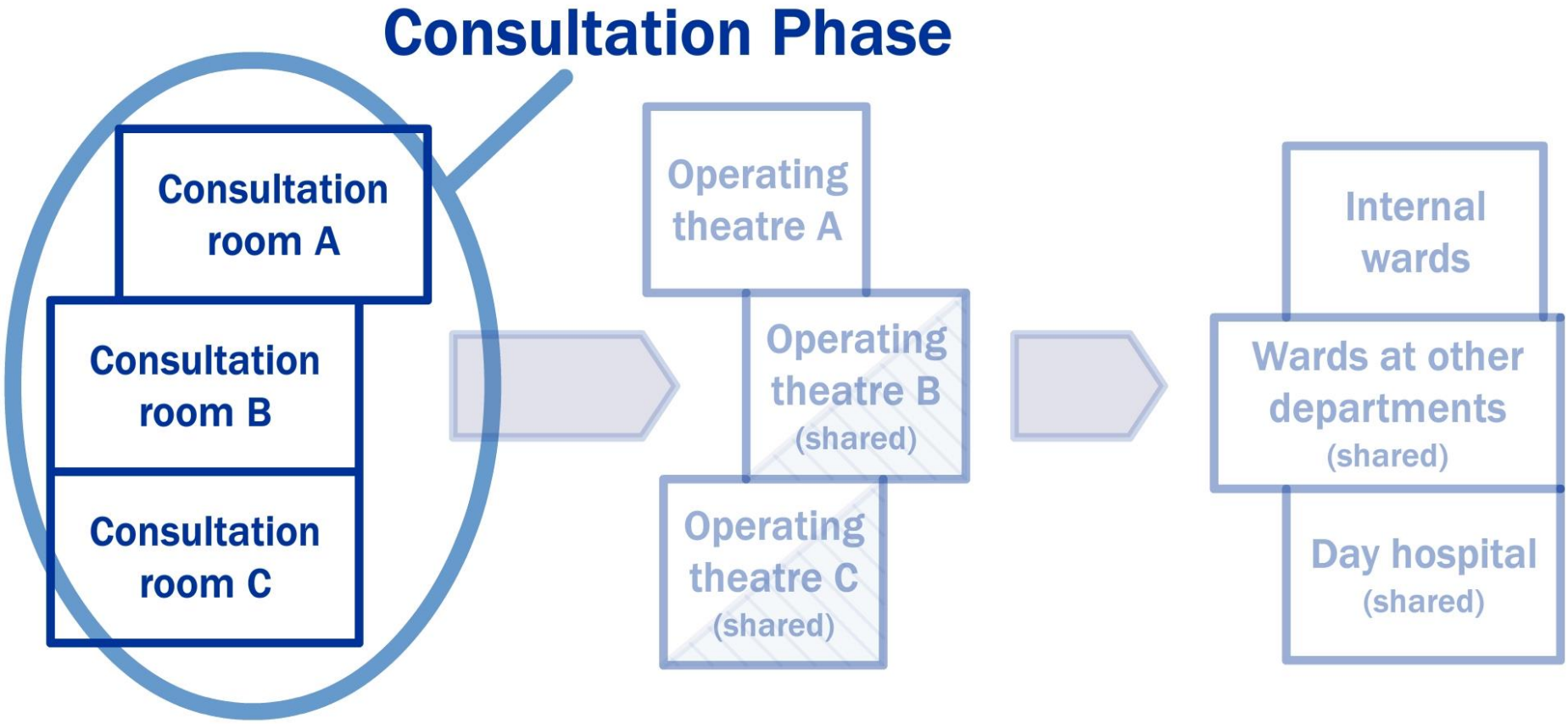
Setting of the Middelheim hospital Antwerpen:

- One of the largest care institutions of the country:
  - 600 beds
  - 75.000 hospitalizations each year
- Orthopaedic department:
  - 3.294 surgeries and over 13.000 consultations in 2005
  - Staff of 6 surgeons and 15 nurses
  - Use of two operating theatres, three consultation offices and a variety of wards (internal, external, day hospital)

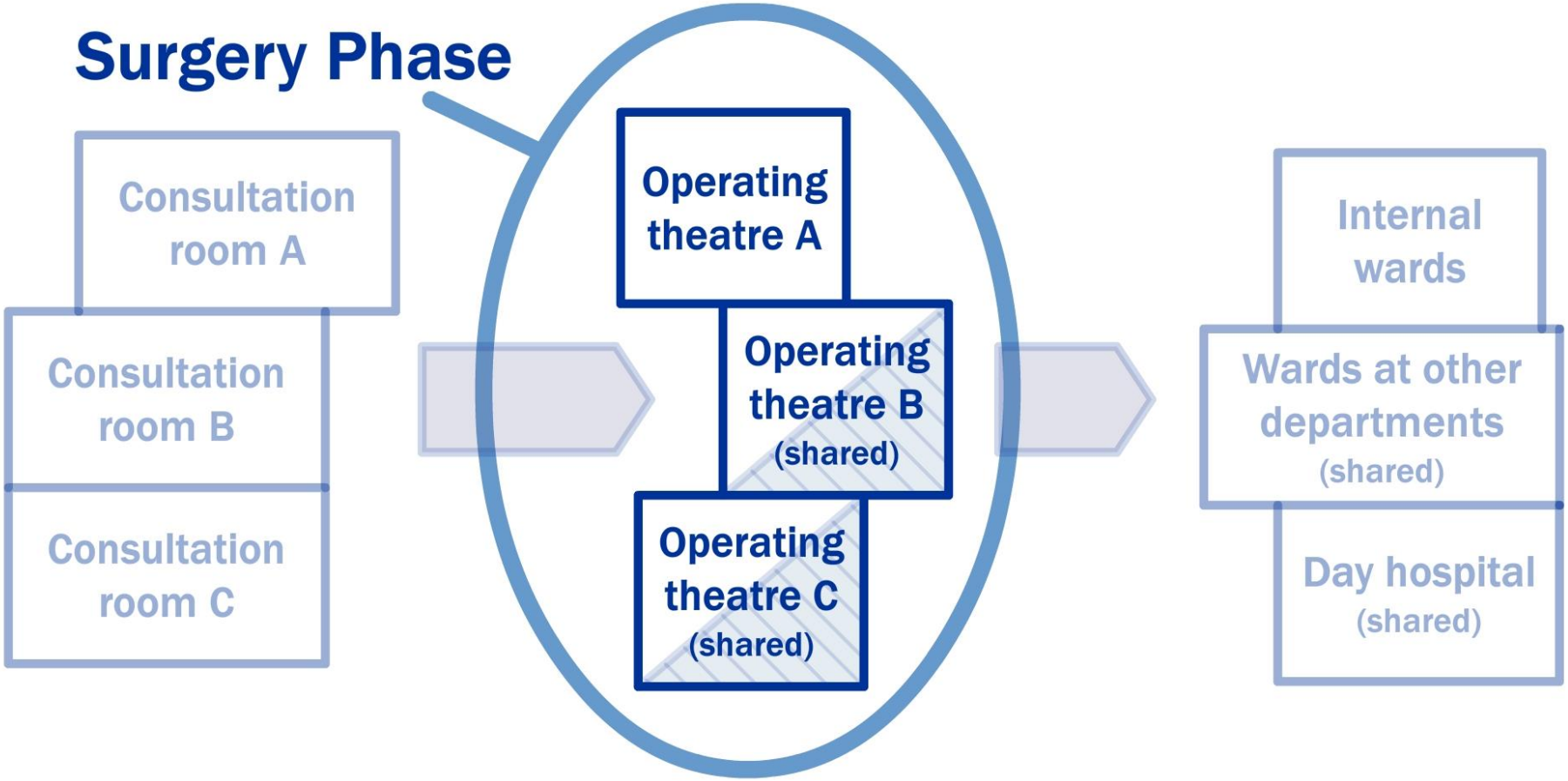
Capacity structure of the orthopaedic division at the Middelheim hospital



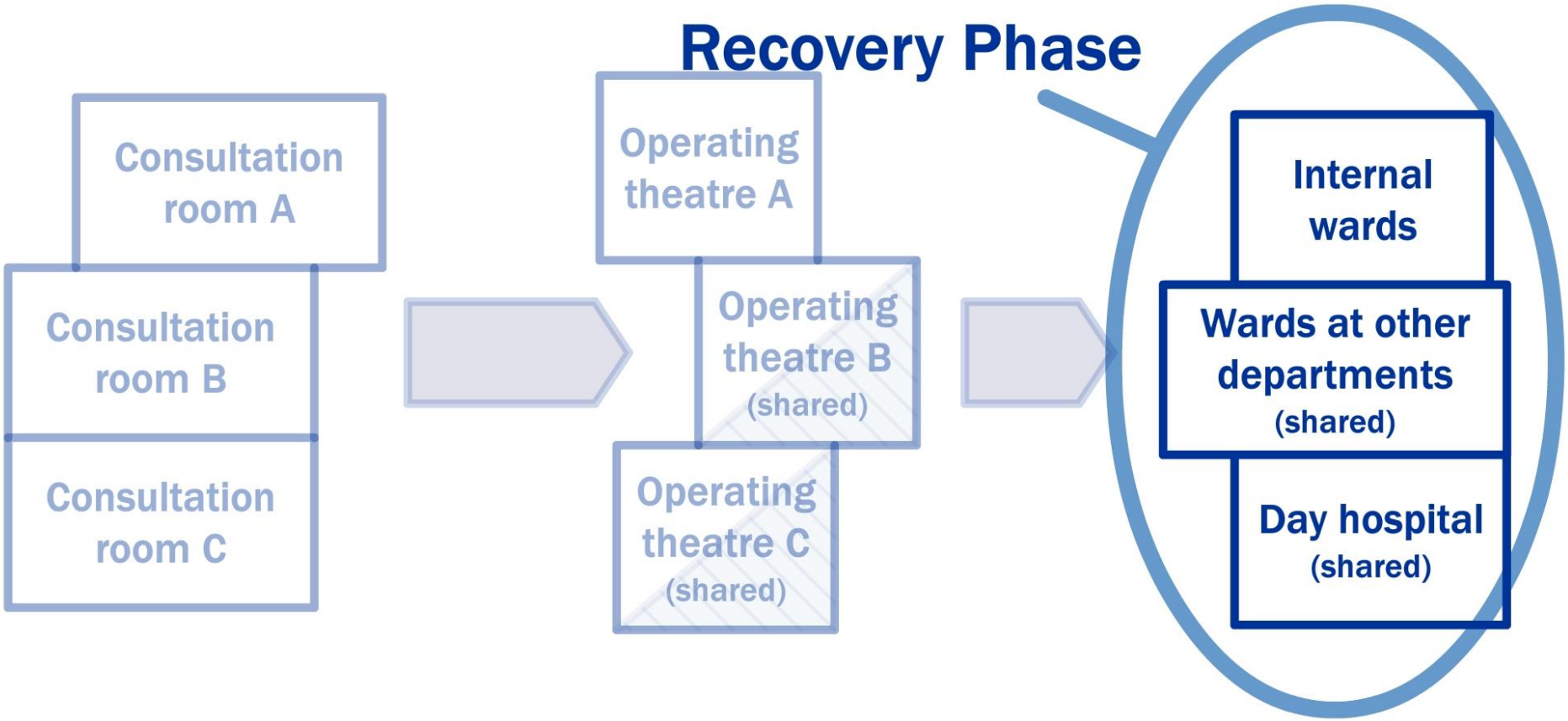
Capacity structure of the orthopaedic division at the Middelheim hospital



Capacity structure of the orthopaedic division at the Middelheim hospital



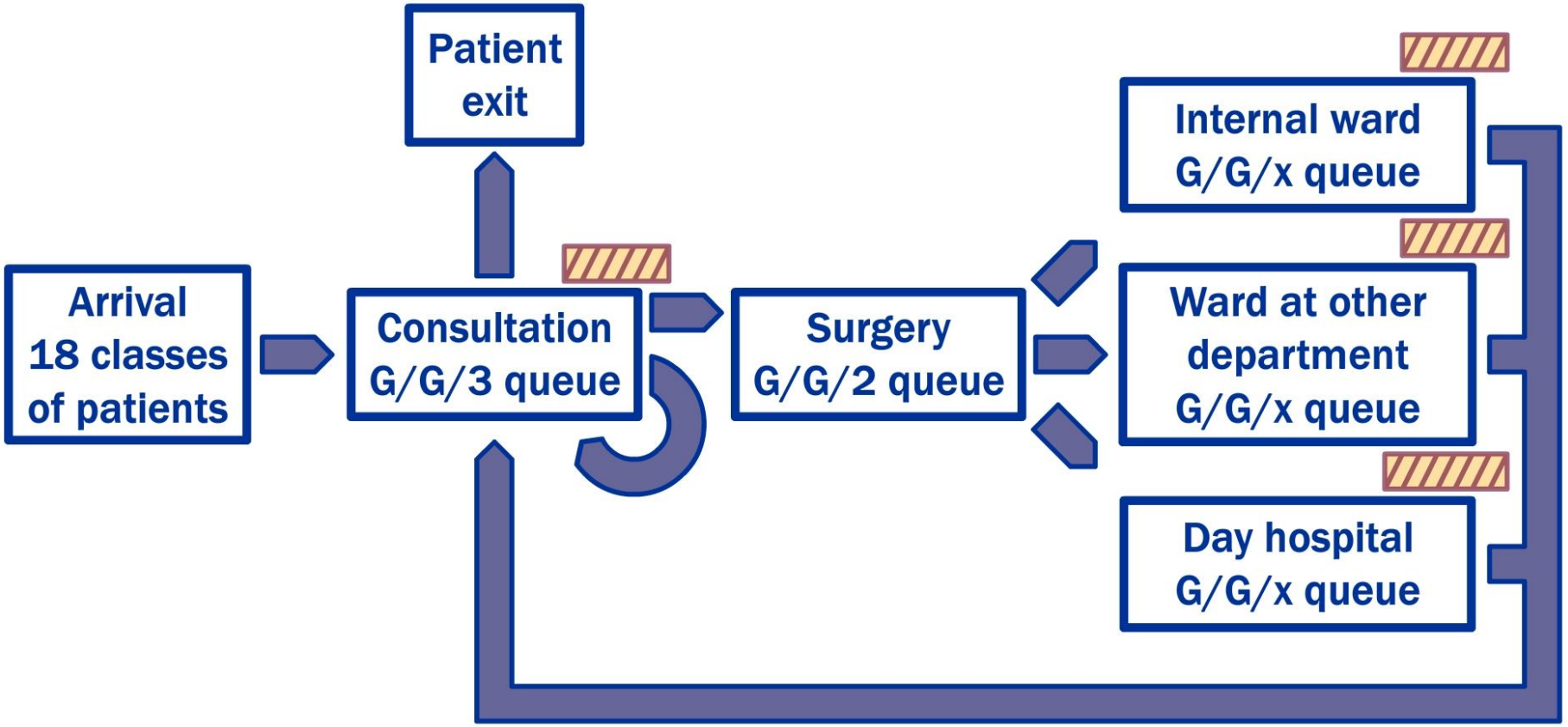
Capacity structure of the orthopaedic division at the Middelheim hospital



- 18 Classes of patients are withheld for modeling purposes:
  - Homogenous
  - Mostly containing only a few DRGs
- Each class has its own properties:
  - Service times at the different nodes in the network (consultation, surgery and recovery)
  - Routing throughout the network (including feedback loops, thereby generating a re-entry of patients and making the system endogenous)

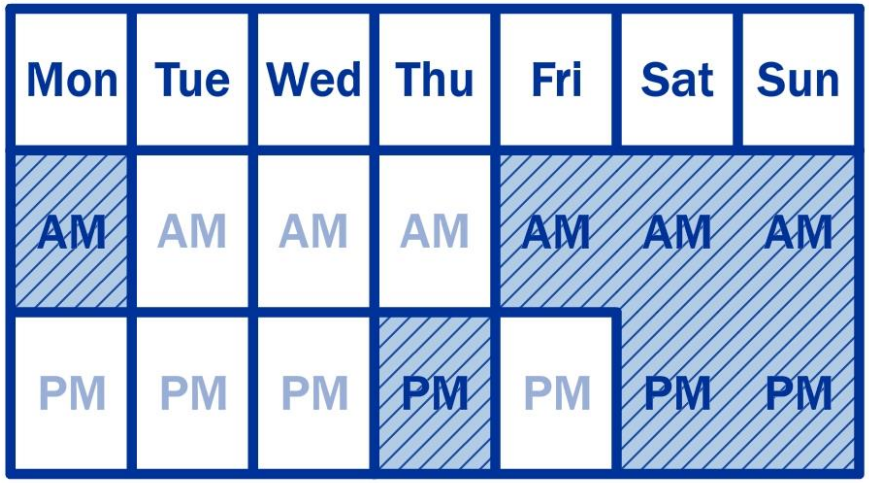
The result is a network of nodes in which 18 classes of patients queue for the consumption of stochastic and limited amount of resources. In order to complete their treatment process, they will follow a stochastic routing throughout the network and will revisit previous stages of the process (i.e. consultation).

Queueing network of the orthopaedic department at the Middelheim hospital



Time tables versus availability

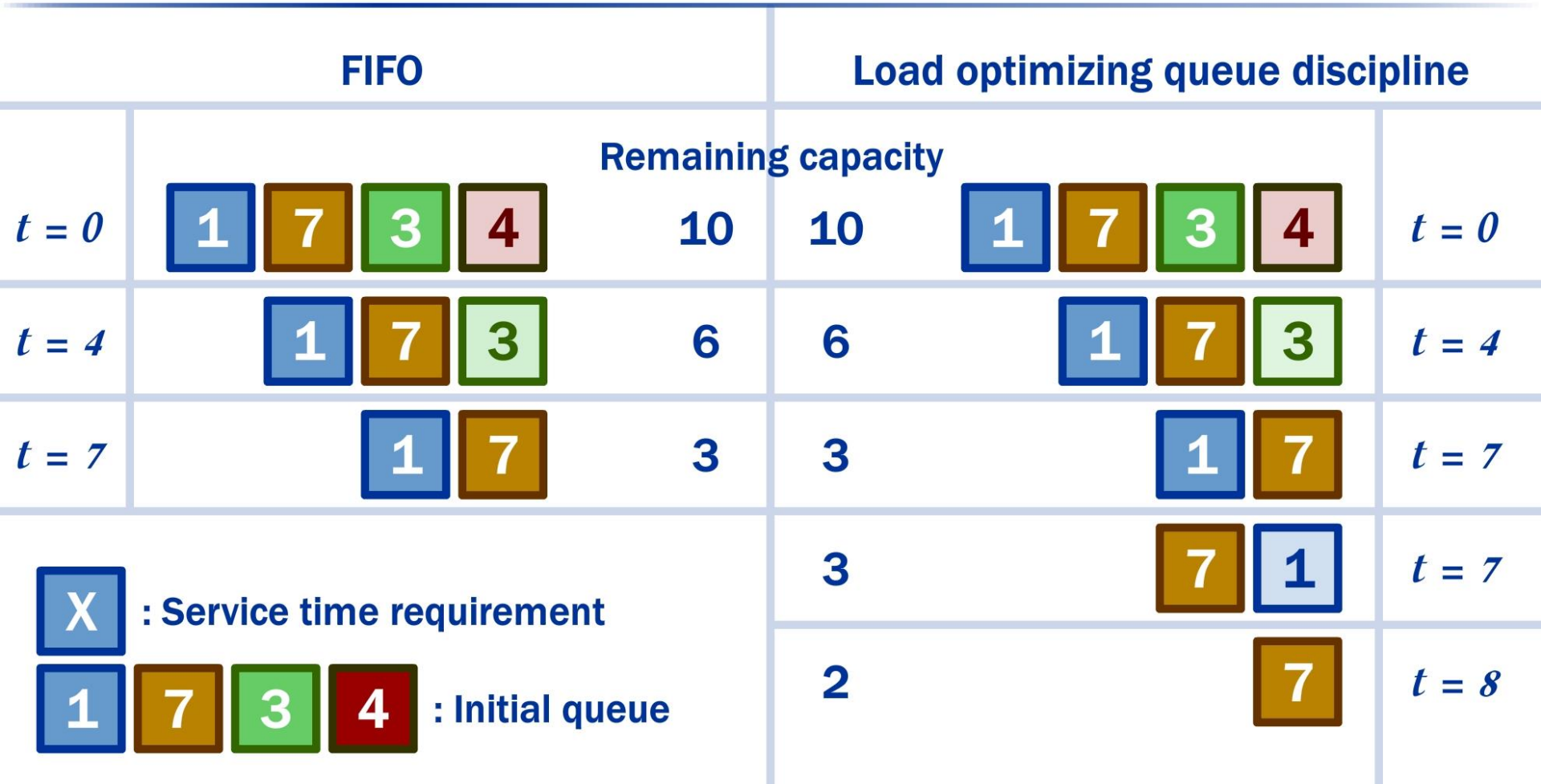
Time table approach



Availability approach

$$t_e = \frac{t_o}{A}$$

FIFO versus load optimizing queue discipline



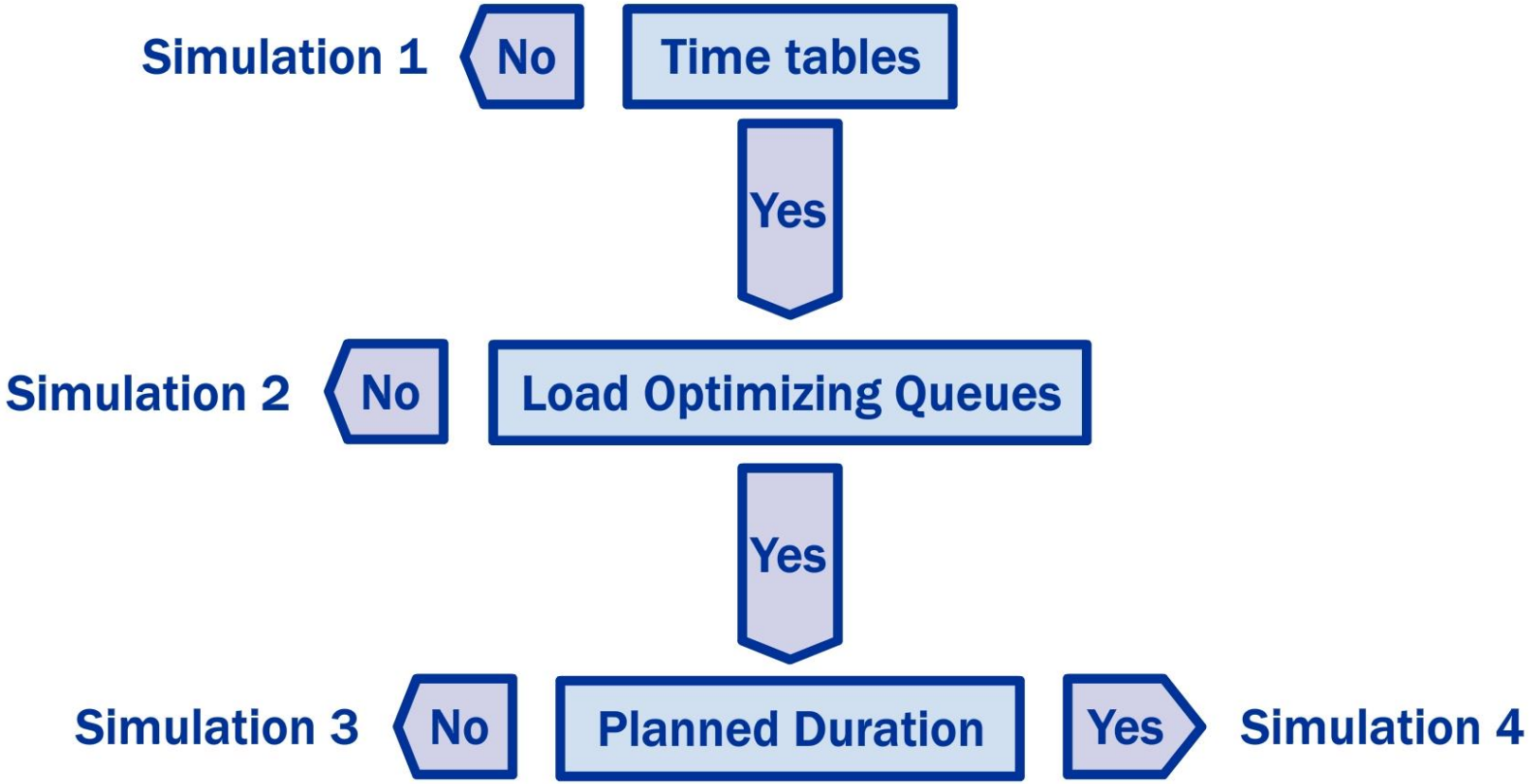
- Planned service times versus real service times:
  - Currently at consultation 15 minutes are scheduled for each consultation, no matter the disorder the patient suffers from.
  - At surgery level the correlation between planned duration and actual surgery time amounts to 0.7663.
  - Both workstations take in unscheduled patients (approximately 5%). These patients are not considered when the planning is drafted.
  - In addition, utilization rates at consultation and surgery approach 100%.
- While process variability (as well as the arrival of unscheduled patients) are unaccounted for in the current approach, even the smallest anomaly leads to increased waiting times, overtime and general inefficiency.

- Purpose of this study:
  - Acquire deeper insight in the applicability of queueing theory on hospital settings.
  - Uncovering the levers required to increase performance at the orthopaedic department of the Middelheim hospital.
  - Observation of the effects of time tables and load optimizing queue disciplines.
- Waiting time and the corresponding waiting list are the performance measures of interest.

- To model this general, multiclass, re-entry queueing network several techniques apply:
  - Simulation
  - Queueing theory; more specifically by means of parametric decomposition models (cf. Jackson, Whitt, Lambrecht among others). To cope with the multiclass and re-entry aspects of the model, aggregation formulas will be used.
- Both approaches have their limitations

- Construction of 4 simulation models to address the issues at hand and their influence on the performance measures:
  - A first model provides support for the 18 classes of patients traversing the system but does not yet incorporate time tables to model when patients will be treated (hence availability is used to determine the effective service times).
  - The second model includes time tables but features FIFO queues in front of the consultation and surgery workstations.
  - The third model applies the load optimizing queue discipline at consultation and surgery workstations.
  - The fourth model takes into account the planned durations.

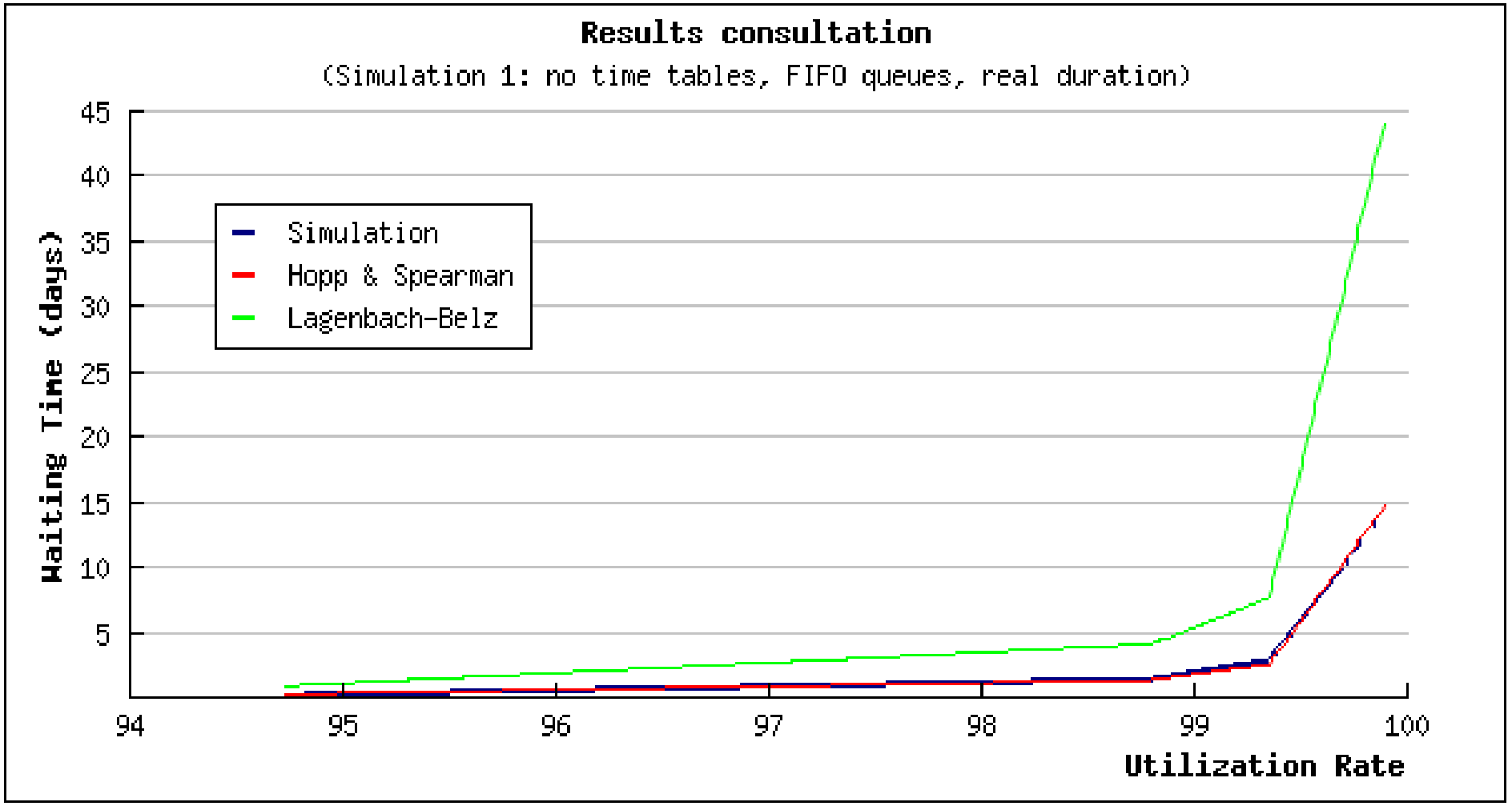
Simulations: Roadmap

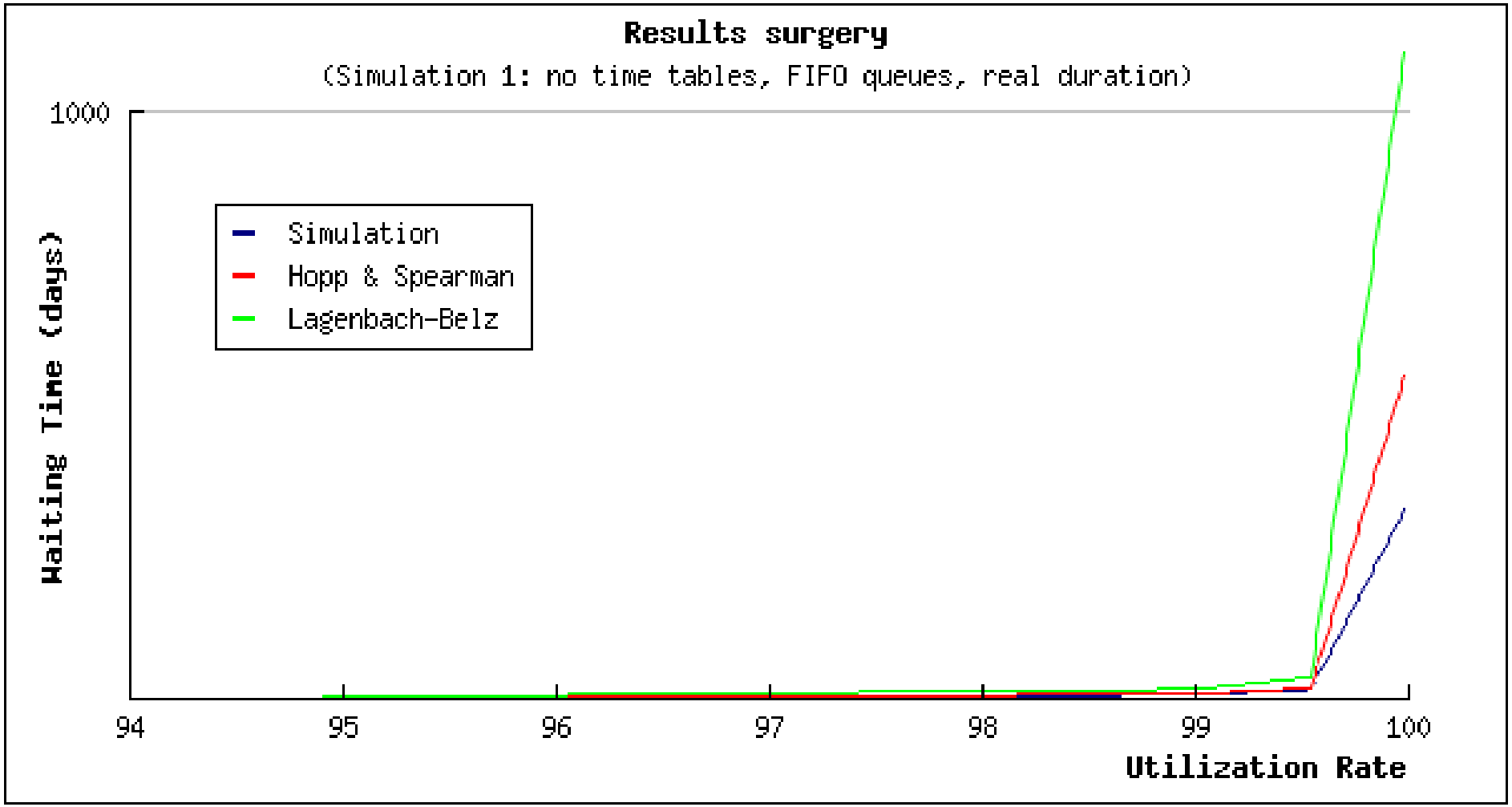


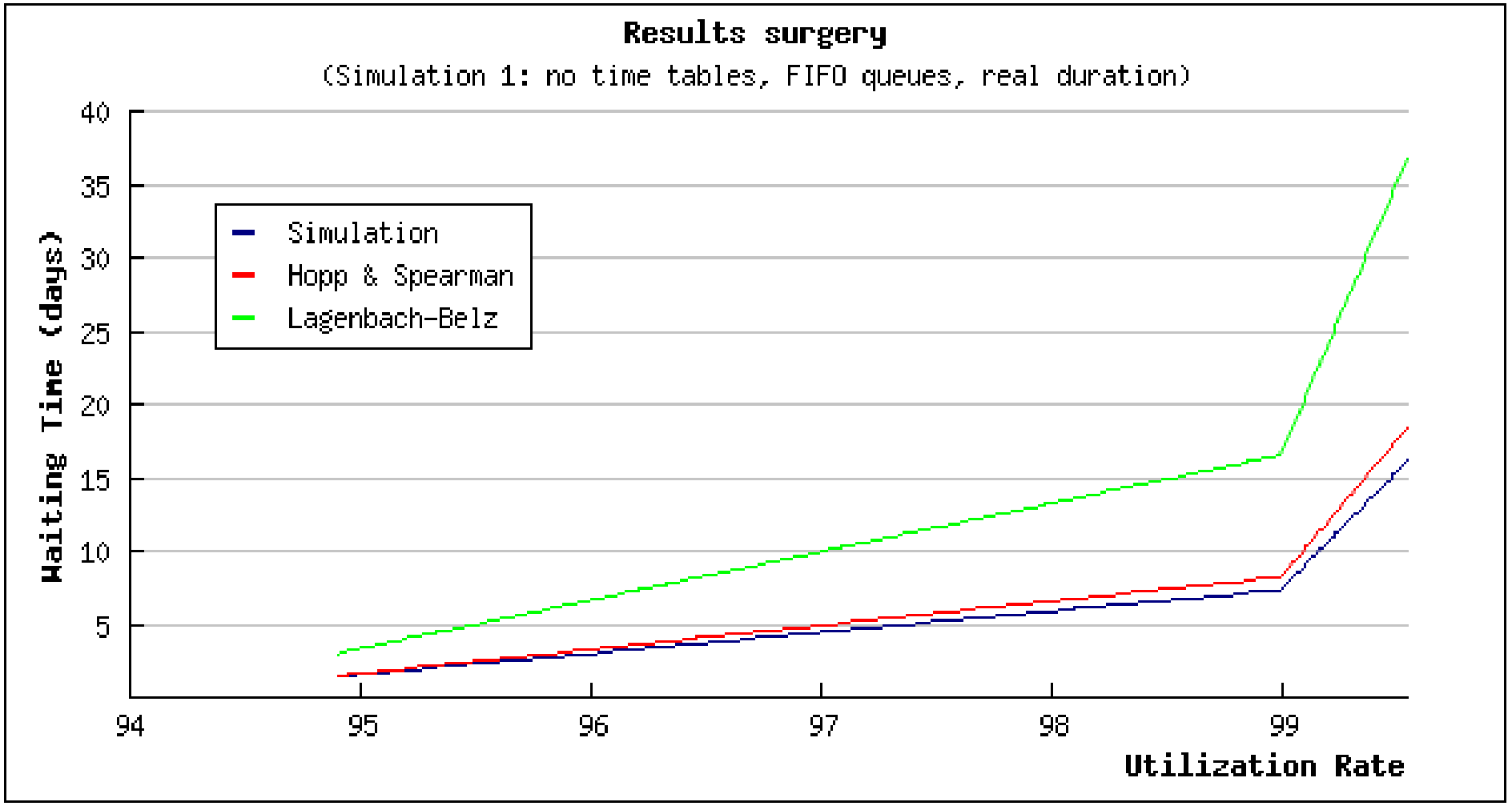
Discussion of the waiting times as a function of utilization rates

Simulation 1 (no time tables, FIFO queues, real duration)	Simulation			
Utilization rate consultation	94.73%	98.79%	99.35%	99.89%
Utilization rate surgery	94.90%	98.99%	99.54%	99.98%
Waiting time consultation (minutes)	467.8549	2179.6752	4278.2973	20598.5277
Waiting time surgery (minutes)	2054.3011	10571.5518	23220.5805	464497.0280
C^2a at consultation	1.0225	0.9556	0.9463	0.9375
C^2a at surgery	0.9436	0.9387	0.9391	0.9384

Waiting times queueing models	Hopp & Spearman			
Waiting time consultation (minutes)	411.9581	1931.8523	3655.9128	21098.1222
Waiting time surgery (minutes)	2132.6181	11851.1213	26425.1636	793551.7044
	Lagenbach-Belz			
Waiting time consultation (minutes)	1292.594914	5854.475098	11026.92631	63353.79803
Waiting time surgery (minutes)	4366.395867	23810.7743	52959.8529	1587213.728

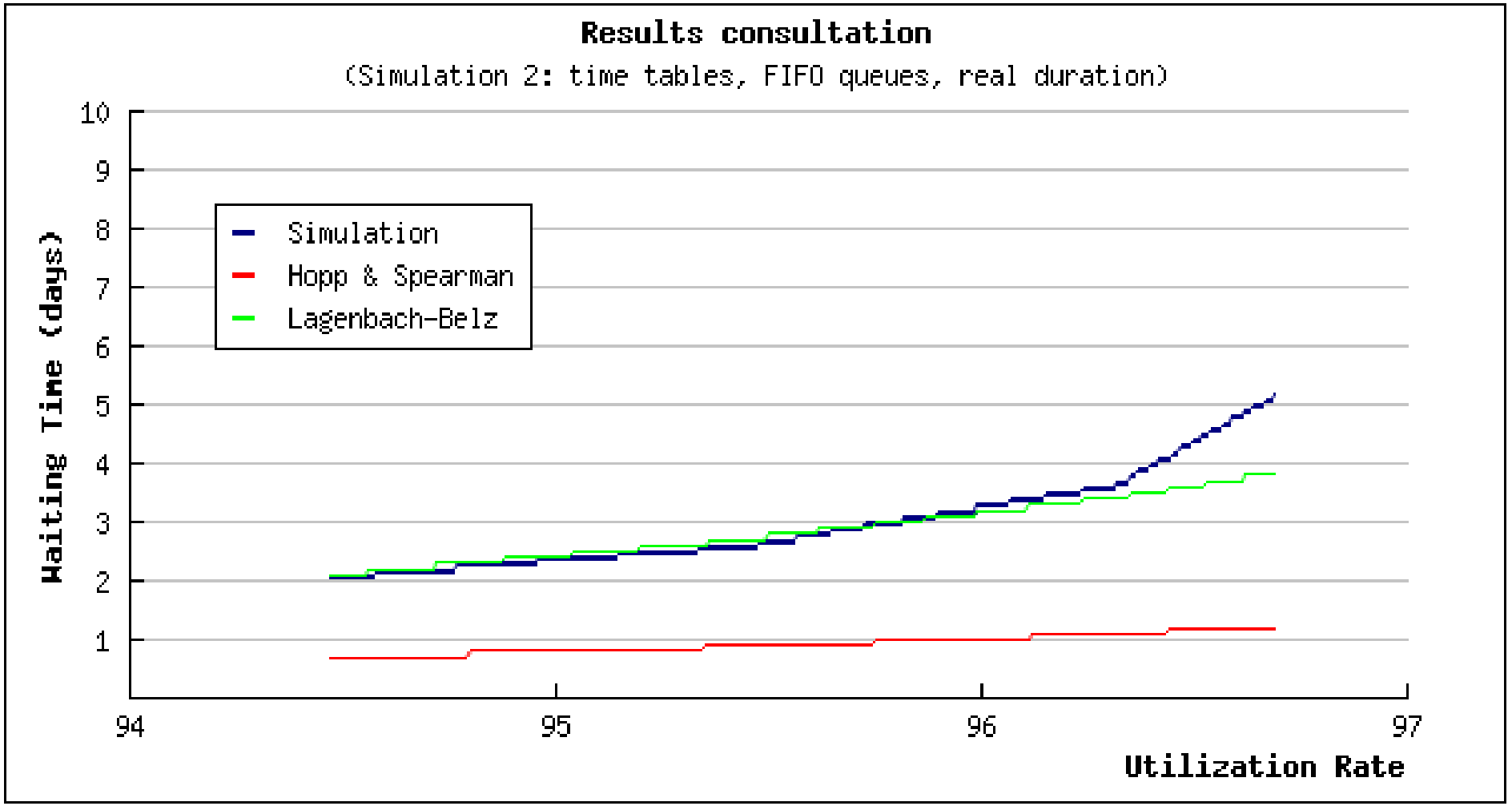

Results consultation
(Simulation 1: no time tables, FIFO queues, real duration)
Waiting Time (days)
45
40
35
30
25
20
15
10
5
Simulation
Hopp & Spearman
Lagenbach-Belz
94
95
96
97
98
99
100
Utilization Rate

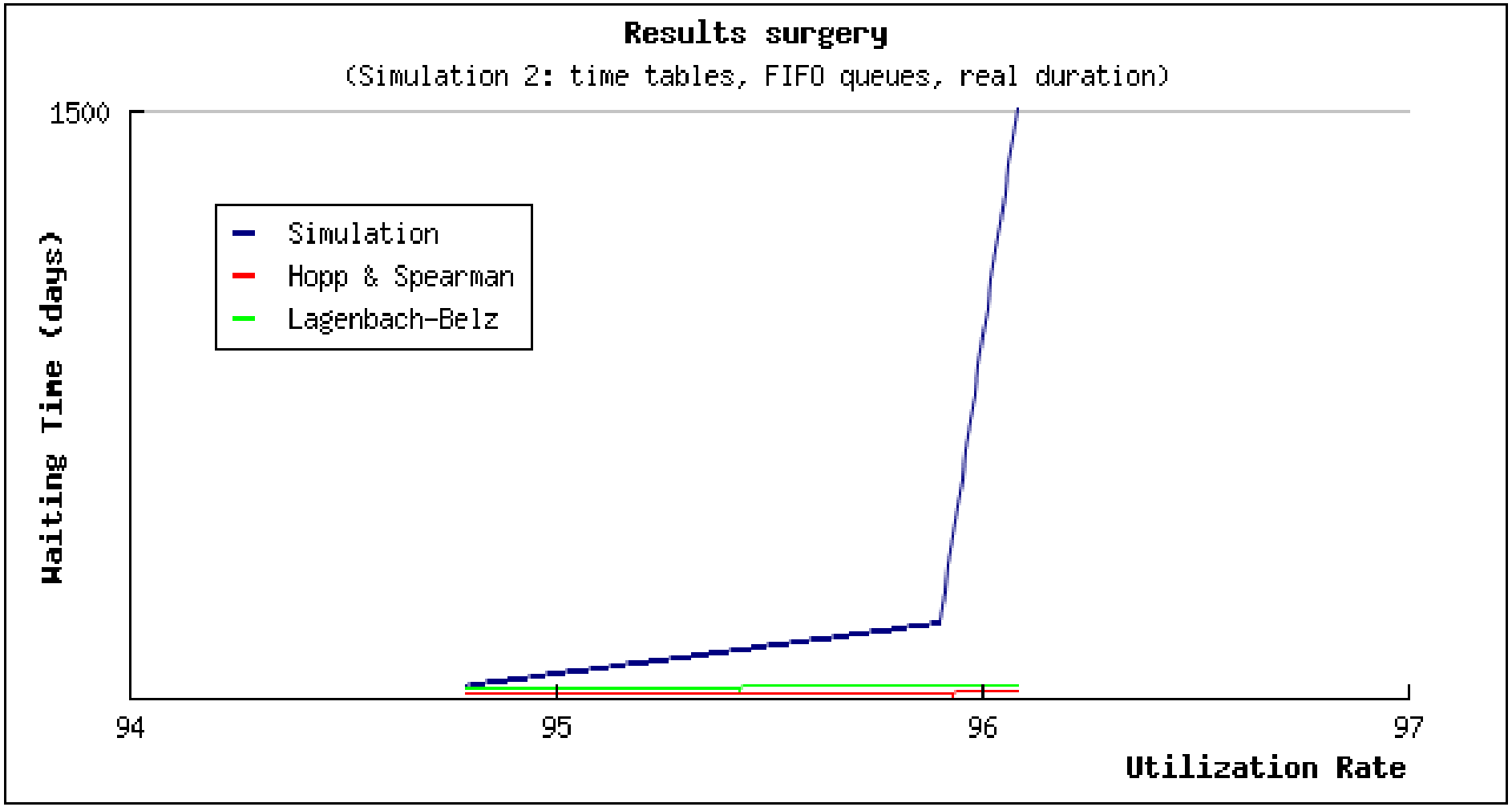

Results surgery
(Simulation 1: no time tables, FIFO queues, real duration)
1000
Waiting Time (days)
Simulation
Hopp & Spearman
Lagenbach-Belz
94
95
96
97
98
99
100
Utilization Rate


Results surgery
(Simulation 1: no time tables, FIFO queues, real duration)
Waiting Time (days)
40
35
30
25
20
15
10
5
Simulation
Hopp & Spearman
Lagenbach-Belz
94
95
96
97
98
99
Utilization Rate

Simulation 2 (time tables, FIFO queues, real duration)	Simulation			
Utilization rate consultation	94.47%	95.44%	96.32%	96.69%
Utilization rate surgery	94.79%	95.90%	96.08%	
Waiting time consultation (minutes)	3014.6458	3748.9816	5263.4515	7439.4602
Waiting time surgery (minutes)	53825.5972	284641.4217	2170228.6612	
C^2a at consultation	3.5965	3.6080	3.6257	3.6288
C^2a at surgery	12.8499	13.1429	13.3370	13.5719

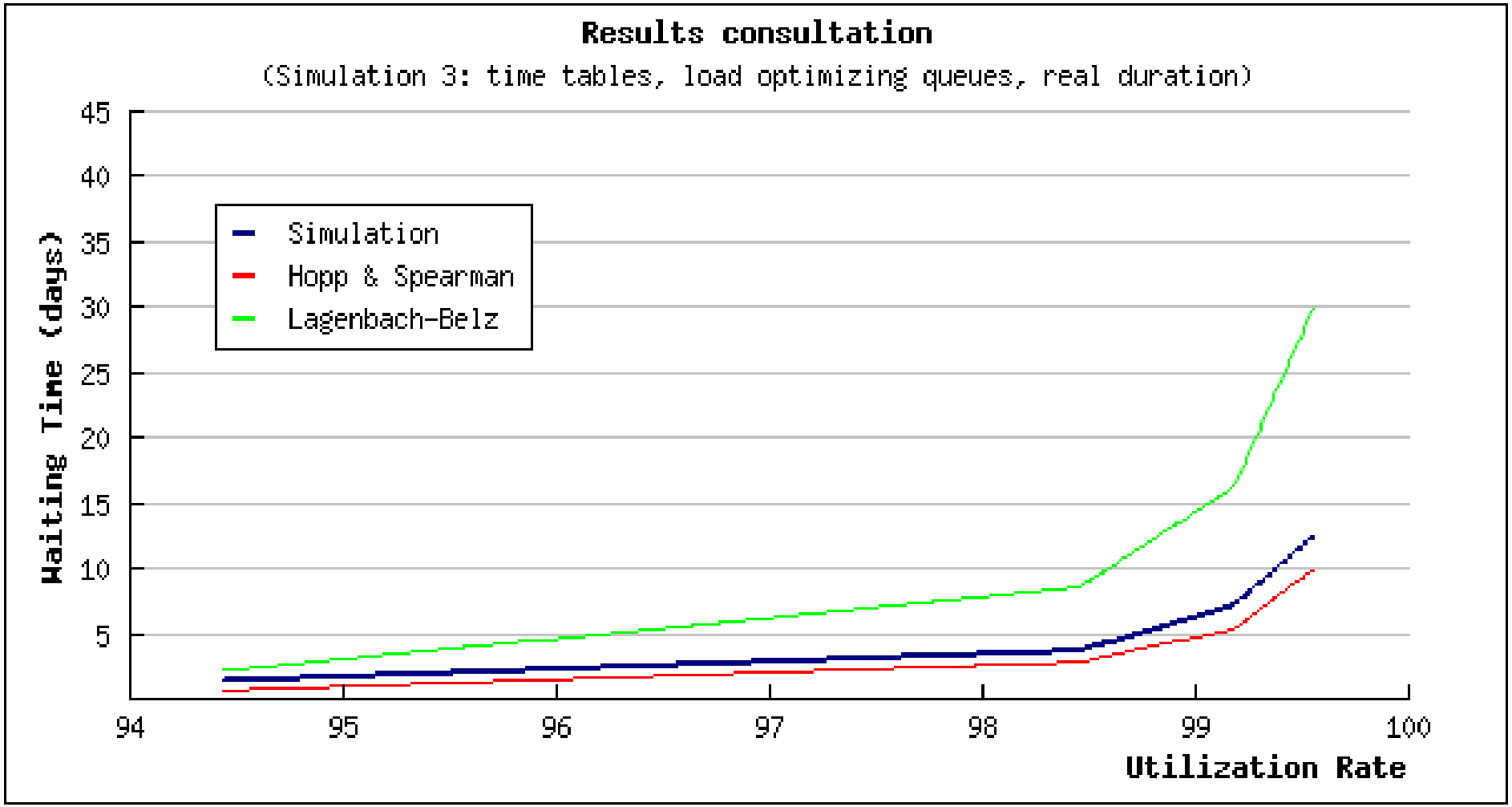
Waiting times queueing models	Hopp & Spearman			
Waiting time consultation (minutes)	995.8530	1248.2991	1592.1479	1790.1238
Waiting time surgery (minutes)	18048.0588	24156.2046	26158.4216	
	Lagenbach-Belz			
Waiting time consultation (minutes)	3131.812025	3892.424078	4927.198769	5522.327678
Waiting time surgery (minutes)	36975.49424	49229.31619	53265.08482	

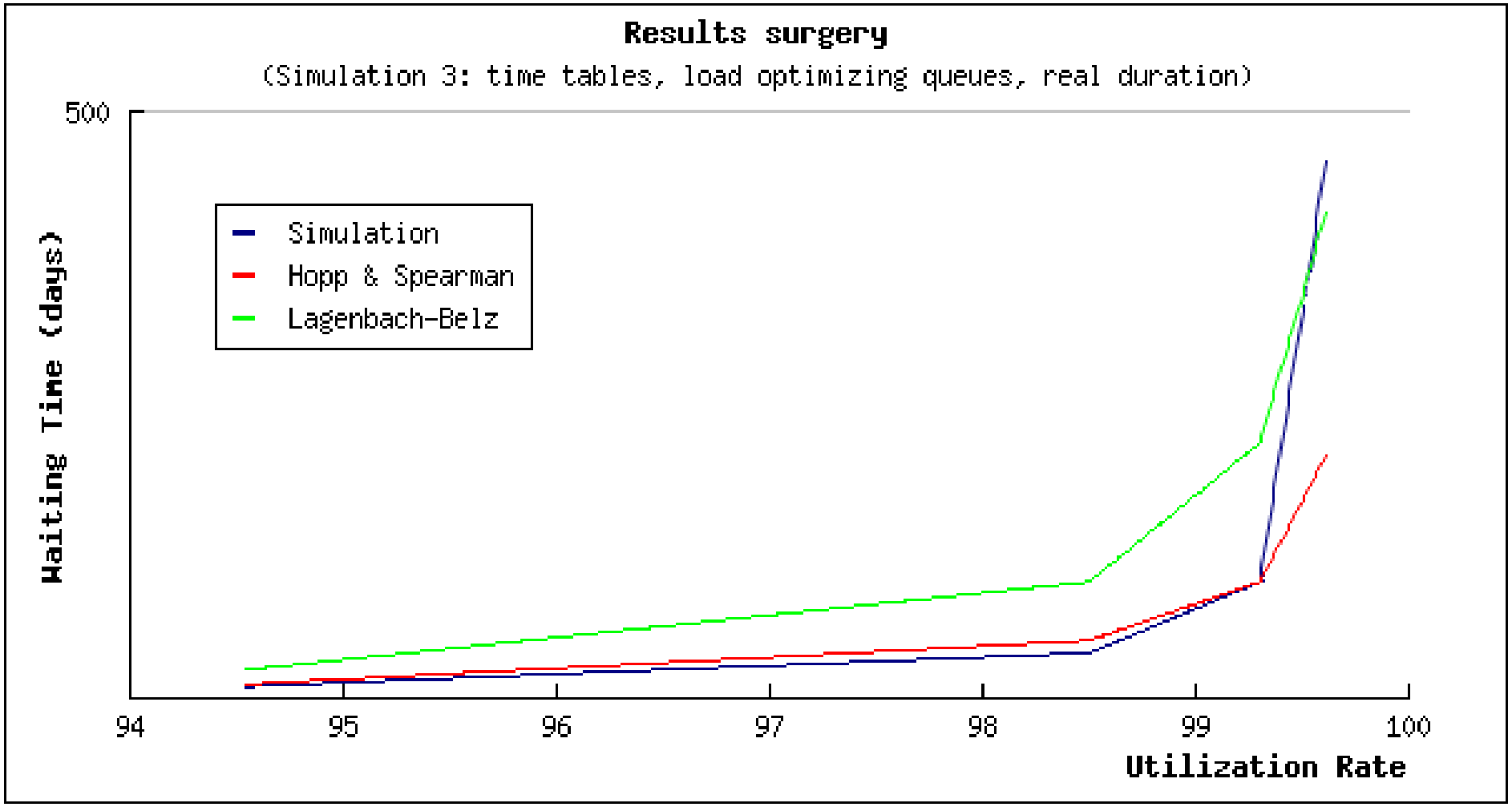

Results consultation
(Simulation 2: time tables, FIFO queues, real duration)
Waiting Time (days)
10
9
8
7
6
5
4
3
2
1
Simulation
Hopp & Spearman
Lagenbach-Belz
94
95
96
97
Utilization Rate


Results surgery
(Simulation 2: time tables, FIFO queues, real duration)
1500
Waiting Time (days)
Simulation
Hopp & Spearman
Lagenbach-Belz
94
95
96
97
Utilization Rate

Simulation 3 (time tables, load optimizing queues, real duration)	Simulation			
Utilization rate consultation	94.44%	98.45%	99.18%	99.55%
Utilization rate surgery	94.54%	98.50%	99.30%	99.61%
Waiting time consultation (minutes)	2229.7136	5501.1885	10526.2957	18061.5283
Waiting time surgery (minutes)	14338.7597	56016.3008	143145.6369	656833.1469
C^2a at consultation	3.5946	3.6384	3.6451	3.6542
C^2a at surgery	12.7921	13.2981	13.2601	13.9307

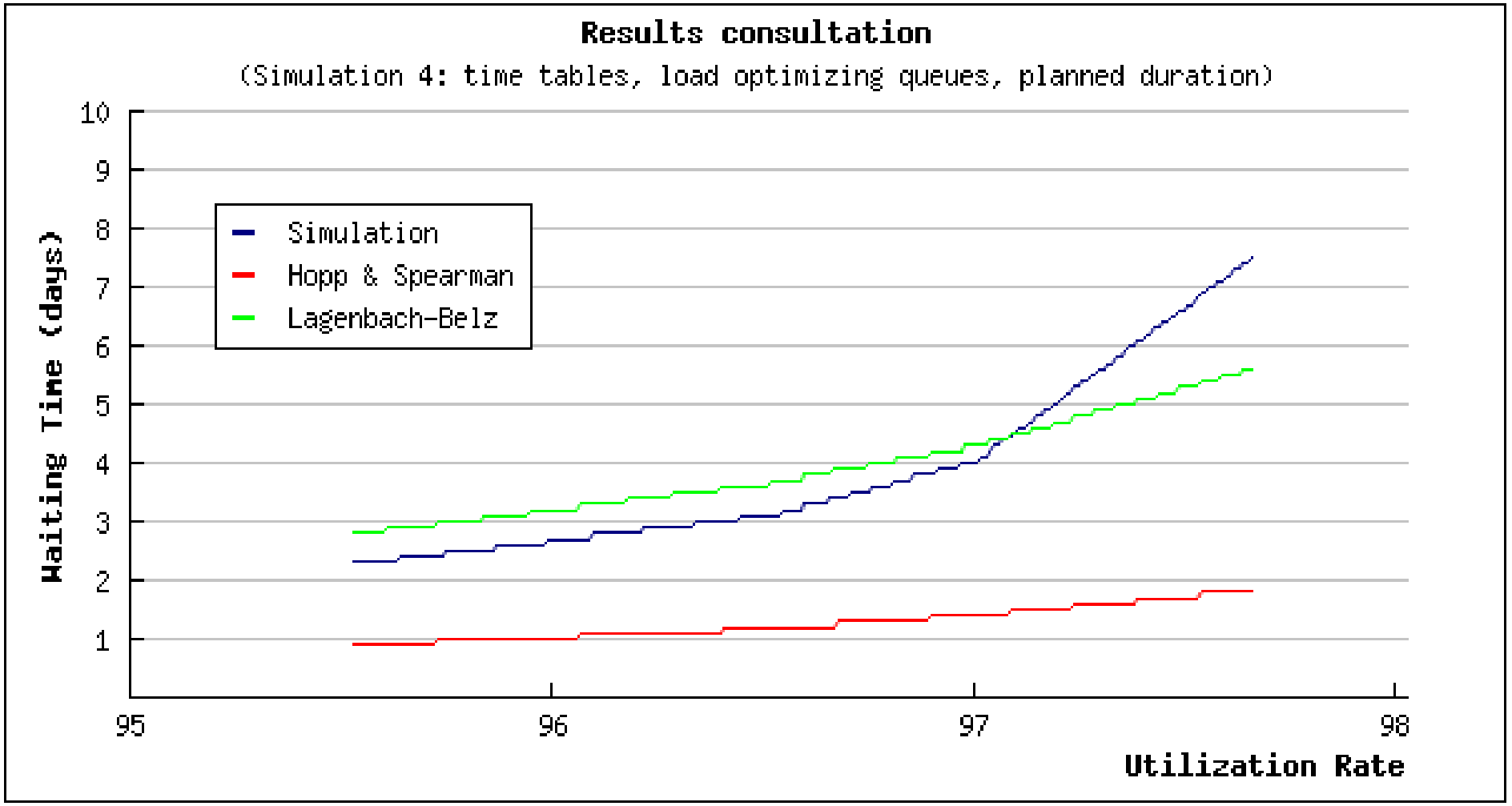
Waiting times queueing models	Hopp & Spearman			
Waiting time consultation (minutes)	989.0015	4042.7929	7757.5484	14316.4512
Waiting time surgery (minutes)	17048.5976	71022.3648	156099.4608	297087.7859
	Lagenbach-Belz			
Waiting time consultation (minutes)	3111.0928	12286.0535	23432.79516	43110.989
Waiting time surgery (minutes)	34968.36951	143015.5673	313180.3172	595210.4898

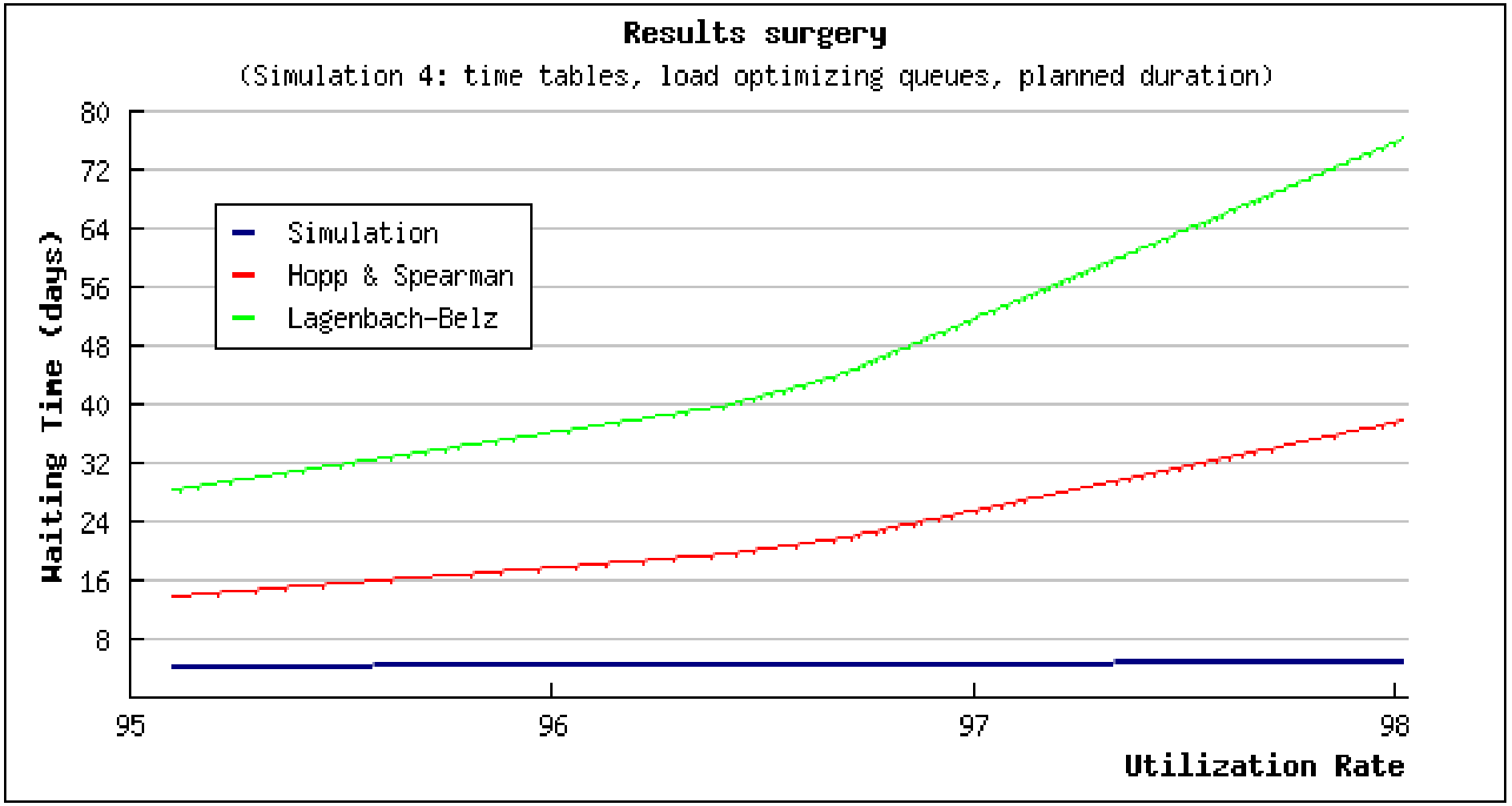

Results consultation
(Simulation 3: time tables, load optimizing queues, real duration)
Waiting Time (days)
45
40
35
30
25
20
15
10
5
Simulation
Hopp & Spearman
Lagenbach-Belz
94
95
96
97
98
99
100
Utilization Rate


Results surgery
(Simulation 3: time tables, load optimizing queues, real duration)
500
Waiting Time (days)
Simulation
Hopp & Spearman
Lagenbach-Belz
94
95
96
97
98
99
100
Utilization Rate

Simulation 4 (time tables, load optimizing queues, planned duration)	Simulation			
Utilization rate consultation	95.53%	96.53%	97.01%	97.66%
Utilization rate surgery	95.10%	96.40%	96.68%	98.02%
Waiting time consultation (minutes)	3260.5709	4491.9753	5817.3969	10787.8311
Waiting time surgery (minutes)	6432.5459	6761.2342	6768.9978	7501.6816
C^2a at consultation	3.6331	3.6479	3.6463	3.6668
C^2a at surgery	13.2790	13.2573	13.4915	13.6108

Waiting times queueing models	Hopp & Spearman			
Waiting time consultation (minutes)	1285.0112	1709.0545	2013.8504	2635.6257
Waiting time surgery (minutes)	19953.1068	28089.8264	31182.1599	54393.1148
	Lagenbach-Belz			
Waiting time consultation (minutes)	4003.721076	5279.356948	6195.160231	8063.188794
Waiting time surgery (minutes)	40818.3865	57112.58889	63317.16147	109770.7562


Results consultation
(Simulation 4: time tables, load optimizing queues, planned duration)
Waiting Time (days)
10
9
8
7
6
5
4
3
2
1
Simulation
Hopp & Spearman
Lagenbach-Belz
95
96
97
98
Utilization Rate


Results surgery
(Simulation 4: time tables, load optimizing queues, planned duration)
Waiting Time (days)
80
72
64
56
48
40
32
24
16
8
Simulation
Hopp & Spearman
Lagenbach-Belz
95
96
97
98
Utilization Rate

- Conclusions:
  - Current planning techniques at the Middelheim hospital have a devastating impact on waiting times.
  - In general the queueing models were able to provide a reasonable result with respect to simulations 1 and 3.
- Key research questions:
  - Effect of the endogenous SCV of the arrivals at the different stations.
  - Effect of a load optimizing queue discipline.
  - Impact of time tables on the SCV of the departures at the different stations.

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