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LEUVEN

Evaluation of appointment scheduling rules
A multi-performance measures approach

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Appointments are part of life

- Car repair
- Accountants
- Dentist
- Barber
- Oral exams
- Internet/cable connecting
- Central heating cleaning
- …

Appointments are frustrating

- Cancellations and no-shows
- Walk-ins and emergencies
- Variability in treatment and arrival times
- Capacity availability
  - Equipement
  - Server

→ Often service providers respond with
overbookings
large appointment timeslots
lateness and no-show fees

→ Long w[illegible]g times
Re-sch[illegible]ules

(Guapta & Denton, 2008)

Service comes to health care

Good service = fulfilling and surpassing expectations

"Patients' Bill of Rights" series on ABC World News
Trend to start invoicing doctors

Delay:
5 $: Dr. Timothy Malia of Fairport, New York,
Starbucks cards: Dr. Gwen Hanson of Bellevue, Washington
Movie tickets: Dr. Sharon McCoy George of Irvine, California
Cancellations:
50 $: Dr. Cyrus Peikari of Dallas, Texas
Smaller number of patients (boutique, concierge practices)

Physician: http://www.kevinmd.com/blog/2012/01/doctors-give-cash-patients-running-late.html)
The Daily: http://www.thedaily.com/page/2012/03/19/031912-news-doctors-paying-patients-1-2/

Importance of
balanced appointment scheduling rules is on the rise

Instead of developing a complex ASR selection tool we want to know which ASR performs well across settings

Appointment scheduling rules research

- **Walk-in systems**
- Open-access (Advanced/online) systems (Murray and Tantau (1999,2000))
  - Customers/patients are scheduled directly when they contact the facility
  - The number of customers/patients to attend is unknown beforehand
  - Capacity chases demand

- **Traditional (offline) system**
- Server/planner has a priori knowledge about the number of patients to attend and possibly their characteristics

  (referral systems)
  - Demand to suit capacity

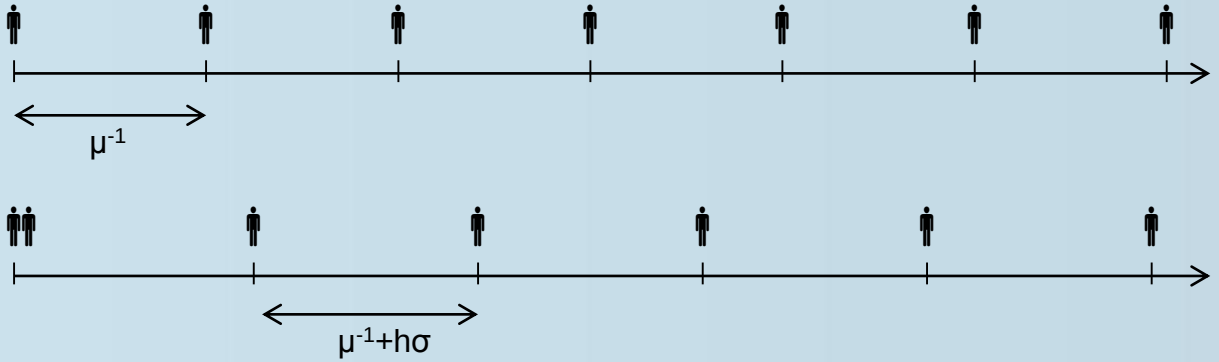
(Robinson & Chen 2010, Liu et al. 2010)

Types of ASR: Finding an ASR that works well in a broad range of settings

Individual ASR

(Bailey, 1952; Rohleder & Klassen, 2000)

- Number of patients to arrive at start of session
- Delay of first patients to arrive
- Adjustment for service variance



Block ASR

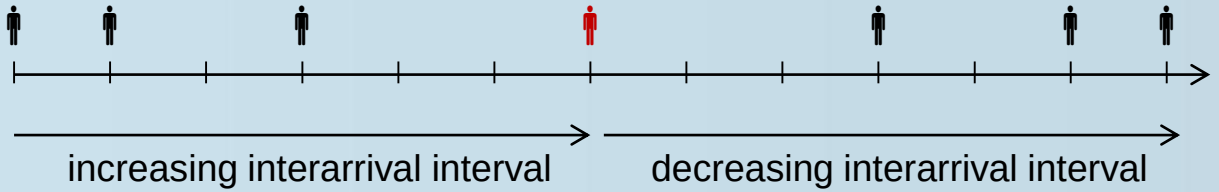
(Liu & Liu, 1998; Vanden Bosch & Dietz, 2002)

- Block size
- Adjustment for service variance

Variable interval (Dome, Early-lateness) **ASR**

(Denton & Gupta, 2003; Wang, 1993)

- The pivot patient
- Speed of increasing or decreasing the arrival pace
- Adjustement for service variance



We identified and tested not less than 314 different ASR

Finding an ASR that works well in a broad range of settings

- Selecting the best ASR:

  (e.g. Ho & Lau, 1992, 1999; Klassen & Yoogalingam, 2009)

  – Customer (direct) waiting time
  – Server idle time
  – Service overtime

  } Cost function: with cost/penalty parameters

Find best/most robust ASR without subjectively imposing a weighting scheme

- Fast and accurate method to obtain performance measures for different ASR
- Data envelopment analysis to identify those ASR that outperfom taking into account multiple performance measures

Fast and accurate method to obtain performance measures for different ASR

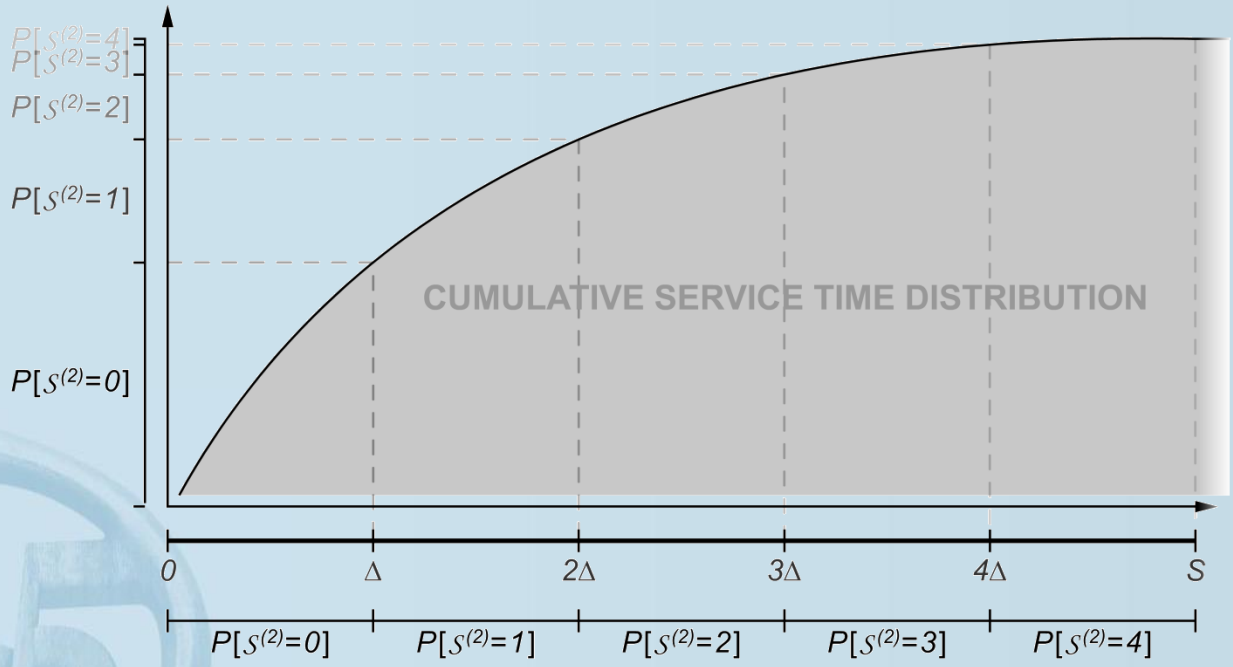
- **Setting**: Schedule N customers in 1 service session; single server
  - Customer unpunctuality: P(too late), P(too early), P(no-show), earliness-lateness distributions
  - Service session delay
  - Stochastic service time and interruptions
- **Technique**: Discrete Time Markov Chain
  - State-space
    - Time instance when system observed
    - The number of customers in queue
    - Set of customers eligible to arrive but still not arrived
    - State of service system: idle, processing or completion

Fast and accurate method to obtain performance measures for different ASR

- **Technique**: Discrete Time Markov Chain

  Transitions

  Events: eligible to arrive, arrival, no-show, service completion



Probabilities: P(state) ⇨ Performance measures: Idle time $(\mathcal{I})$

Waiting time $(\mathcal{W})$

Overtime $(\mathcal{O})$

Identify those ASR that outperfom taking into account multiple performance measures

- **Setting**: 314 ASR with performance measures $\mathcal{I}, \mathcal{W}, \mathcal{O}$

  for 243 operating environments :

  N, SCV(service), SCV(early), SCV(late), P(early), P(late), P(no-show)

- **Technique**: Data envelopment analysis
  - Composite indicator

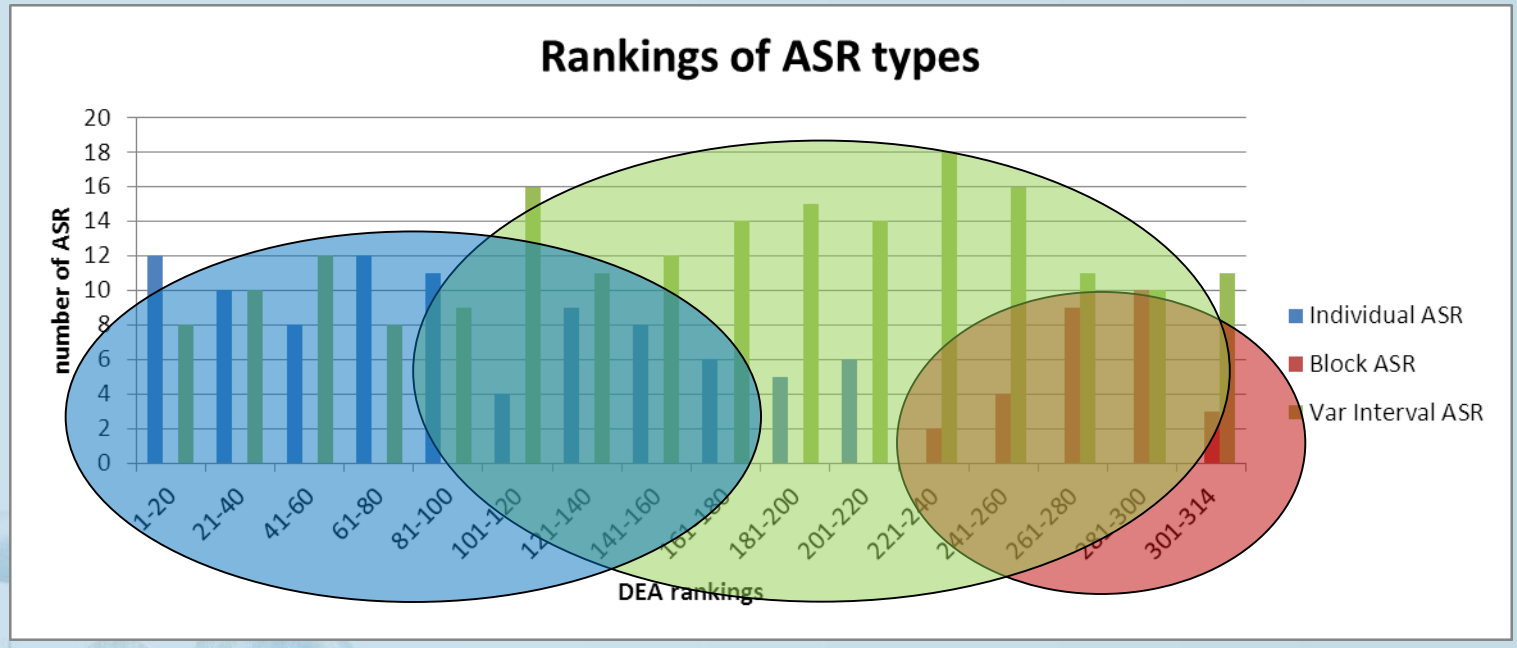
    $CI_r = v_{or}\mathcal{O}_r + v_{ir}\mathcal{I}_r + v_{wr}\mathcal{W}_r$
  - Setting weight objectively:

    input oriented DEA without output (Cherchye et al., 2008)
  - Avoid zero weights:

    constrained facet analysis (CFA) (Olesen & Petersen, 1996)

For each ASR we obtain one score which aggregates multiple-performance measures across different environments

Which type of ASR performs strongly?



Individual ASR outperform the other types of ASR

Top 15 performing ASR

Rank	ASR	CI (%)	Weight Sensitivity	Type of ASR	Characteristics
1	15	99,998	0,195624	Indiv	first arrival delay=0 Nr of initial patient=3 adjustment time var=0
2	22	99,9976	0,313921	Indiv	first arrival delay=0 Nr of initial patient =4 adjustment time var=0
3	30	99,9964	0,389075	Indiv	first arrival delay=0 Nr of initial patient=5 adjustment time var=0,05
4	23	99,9954	0,284273	Indiv	first arrival delay=0 Nr of initial patient=4 adjustment time var=0,05
5	29	99,9941	0,412453	Indiv	first arrival delay=0 Nr of initial patient=5 adjustment time var=0
6	16	99,9838	0,163625	Indiv	first arrival delay=0 Nr of initial patient=3 adjustment time var=0,05
7	228	99,9724	0,066703	Var Interval	pivot patient=15 rate interval increase=2 decrease=1 adjustment time var=0,05
8	138	99,965	0,171877	Var Interval	pivot patient =5 rate interval increase=1 decrease=1 adjustment time var=0,2
9	214	99,9453	0,070306	Var Interval	pivot patient =15 rate interval increase=1 decrease=1 adjustment time var=0,1
10	247	99,9184	0,064002	Var Interval	pivot patient =20 rate interval increase=1 decrease=0 adjustment time var=0,1
11	31	99,906	0,364031	Indiv	first arrival delay=0 Nr of initial patient=4 adjustment time var=0,1
12	7	99,8875	0,340854	Indiv	first arrival delay=0 Nr of initial patient=1 adjustment time var=0,3
13	267	99,8871	0,063741	Var Interval	pivot patient=20 rate interval increase=2 decrease=1 adjustment time var=0,05
14	9	99,8838	0,076893	Indiv	first arrival delay=0 Nr of initial patient=2 adjustment time var=0,05
15	176	99,872	0,095337	Var Interval	pivot patient=10 rate interval increase=1 decrease=1 adjustment time var=0,15
⋮					
23	8	99,8136	0,09592	Indiv	first arrival delay=2 Nr of initial patients=2 adjustment time var=0

Best 7 individual ASR: no delay in first arrival

3 or more patient at start of session

adjustment for service variance should be zero or very small

Service comes to health care

Limiting customer waiting time is often crucial to satisfy customers

We adapt the DEA model
such that customer waiting time has the highest weight in the performance evaluation

$$\frac{v_w}{v_i} \geq 1 \qquad \frac{v_w}{v_o} \geq 1$$

If customer waiting time has highest importance

Rank	ASR	CI (%)	Weight Sensitivity	Type of ASR	Characteristics
1	228	99,97242	0,050776	Var Interval	pivot patient=15 rate interval increase=2 decrease=1 adjustment time var=0,05
2	138	99,96501	0,114976	Var Interval	pivot patient =5 rate interval increase=1 decrease=1 adjustment time var=0,2
3	214	99,94535	0,053322	Var Interval	pivot patient =15 rate interval increase=1 decrease=1 adjustment time var=0,1
4	247	99,91838	0,054437	Var Interval	pivot patient =20 rate interval increase=1 decrease=0 adjustment time var=0,1
5	7	99,88746	0,273575	Indiv	first arrival delay=0 Nr of initial patient=1 adjustment time var=0,3
6	267	99,88713	0,053451	Var Interval	pivot patient=20 rate interval increase=2 decrease=1 adjustment time var=0,05
7	176	99,87204	0,073426	Var Interval	pivot patient=10 rate interval increase=1 decrease=1 adjustment time var=0,15
8	70	99,85562	0,192716	Indiv	first arrival delay=0,5 Nr of initial patient=2 adjustment time var=0,3
9	175	99,84572	0,06281	VariInterval	pivot patient=10 rate interval increase=1 decrease=1 adjustment time var=0,1
10	69	99,8433	0,150799	Indiv	first arrival delay=0,5 Nr of initial patient=2 adjustment time var=0,25
11	139	99,83446	0,138516	Var Interval	pivot patient=5 rate interval increase=1 decrease=1 adjustment time var=0,25
12	68	99,83392	0,114452	Indiv	first arrival delay=0,5 Nr of initial patient=2 adjustment time var=0,2
13	208	99,82541	0,051386	Var Interval	pivot patient =15 rate interval increase=1 decrease=0 adjustment time var=0,1
14	152	99,7837	0,087551	Var Interval	pivot patient =5 rate interval increase=2 decrease=1 adjustment time var=0,15
15	137	99,78285	0,094437	Var Interval	pivot patient =5 rate interval increase=1 decrease=1 adjustment time var=0,15
⋮					
37	8	99,5372	0,052692	Indiv	first arrival delay=2 Nr of initial patients=2 adjustment time var=0

Variable interval ASR take over as best performing ASR

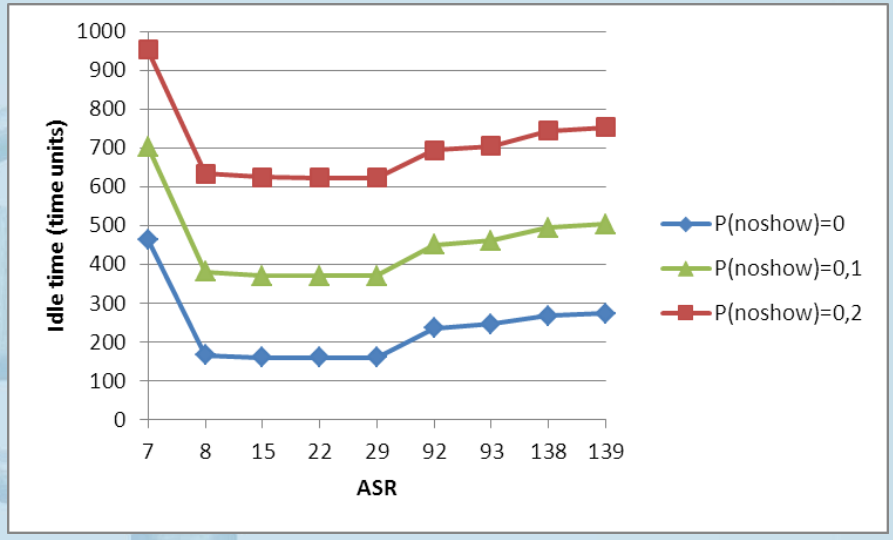
<u>Top four Var interval ASR:</u> perform very strong across different weighting schemes

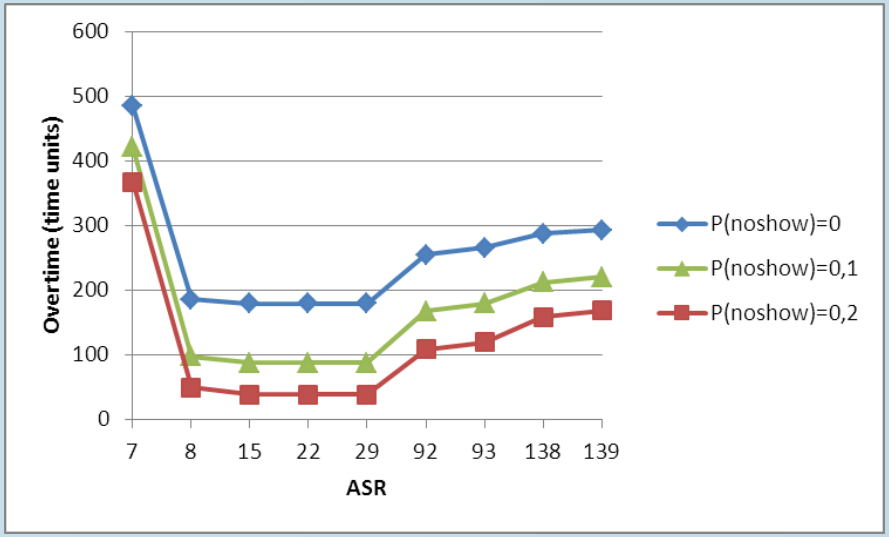
Which environmental factor influence the performance the most?

Environmental effects studied

- P(late); P(early)
- SCV(late); SCV(early)
- N
- P(no-show)
- SCV(service time)

We identify no-shows as the environment factor with the most detrimental effect on performance





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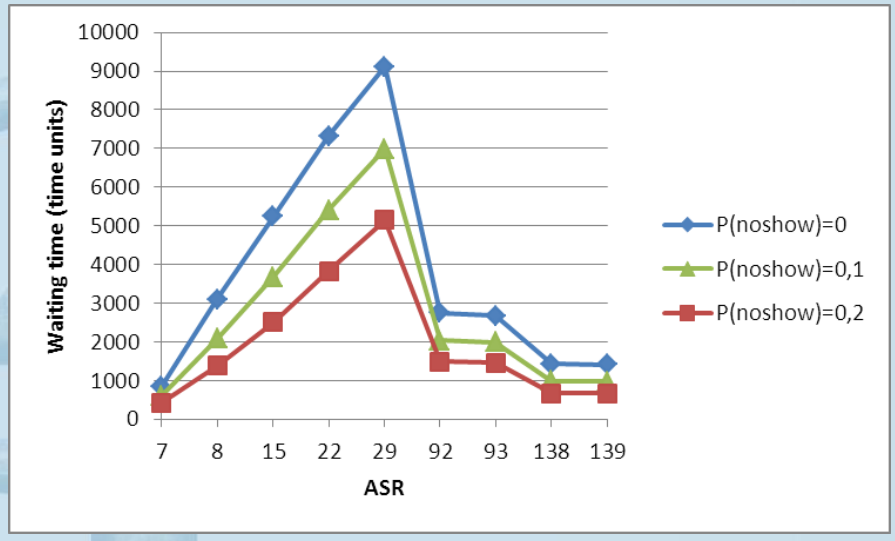


No-shows are not only detrimental but also prevalent in healthcare

- "No-show rates at medical centers can vary from as little as **3%** to as much as **80%** depending on the type of center and demographic information of the patients of the medical Center" (Alaeddini et al., 2011)
- Quoted average values vary e.g. **42%** (Lacy et al., 2004), **10-25%** (Pinedo, 2012)
- US national level study revealed that one third of all family practice residencies had over **21%** no-shows of appointments (Hixon et al. 1999)

Adapted ASR to deal with no-shows (Cayirli et al., 2012)

Which (standard) ASR perform strongly under high amount of no-shows?

Under high no-shows

Rank	ASR	CI (%)	Weight Sensitivity	Type of ASR	Characteristics
1	29	99,9998	0,3921	Indiv	first arrival delay=0 Nr of initial patient=5 adjustment time var=0
2	22	99,9996	0,2892	Indiv	first arrival delay=0 Nr of initial patient=4 adjustment time var=0
3	15	99,9994	0,1732	Indiv	first arrival delay=0 Nr of initial patient=3 adjustment time var=0
4	285	99,9978	0,0518	Var Interval	pivot patient =25 rate interval increase=1 decrease=0 adjustment time var=0,05
5	30	99,9971	0,3687	Indiv	first arrival delay=0 Nr of initial patient=5 adjustment time var=0,05
6	175	99,9966	0,0700	Var Interval	pivot patient=10 rate interval increase=1 decrease=1 adjustment time var=0,1
7	7	99,9891	0,3217	Indiv	first arrival delay=0 Nr of initial patient=1 adjustment time var=0,3
8	23	99,9862	0,2610	Indiv	first arrival delay=0 Nr of initial patient=4 adjustment time var=0,05
9	8	99,9709	0,0839	Indiv	first arrival delay=0 Nr of initial patient=2 adjustment time var=0
10	291	99,9696	0,0520	Var Interval	pivot patient =25 rate interval increase=1 decrease=1 adjustment time var=0,05
11	189	99,9644	0,0567	Var Interval	pivot patient=10 rate interval increase=2 decrease=1 adjustment time var=0,05
12	**138**	99,9601	0,1645	Var Interval	pivot patient =5 rate interval increase=1 decrease=1 adjustment time var=0,2
13	151	99,9578	0,1154	Var Interval	pivot patient =5 rate interval increase=2 decrease=1 adjustment time var=0,1
14	16	99,9559	0,1447	Indiv	first arrival delay=0 Nr of initial patient=3 adjustment time var=0,05
15	**228**	99,9487	0,0564	Var Interval	pivot patient =15 rate interval increase=2 decrease=1 adjustment time var=0,05
…					
24	**214**	99,8833	0,0609	Var Interval	pivot patient =15 rate interval increase=1 decrease=1 adjustment time var=0,1
31	**247**	99,8066	0,0543	Var Interval	pivot patient =20 rate interval increase=1 decrease=0 adjustment time var=0,1

Bailey-Welch rules perform strong

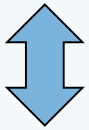
Also the robust Var interval ASR perform strongly but are beaten by more simple rules

Findings

We develop a fast and accurate analytical model based on DTMC and DEA to assess the performance of ASR

314 ASR were compared across 243 environmental setting based on three performance measures (overtime, idle time and waiting time)

Individual ASR perform strongly especially w.r.t. overtime and idle time: thanks to arrival of buffer patients at the start of the session



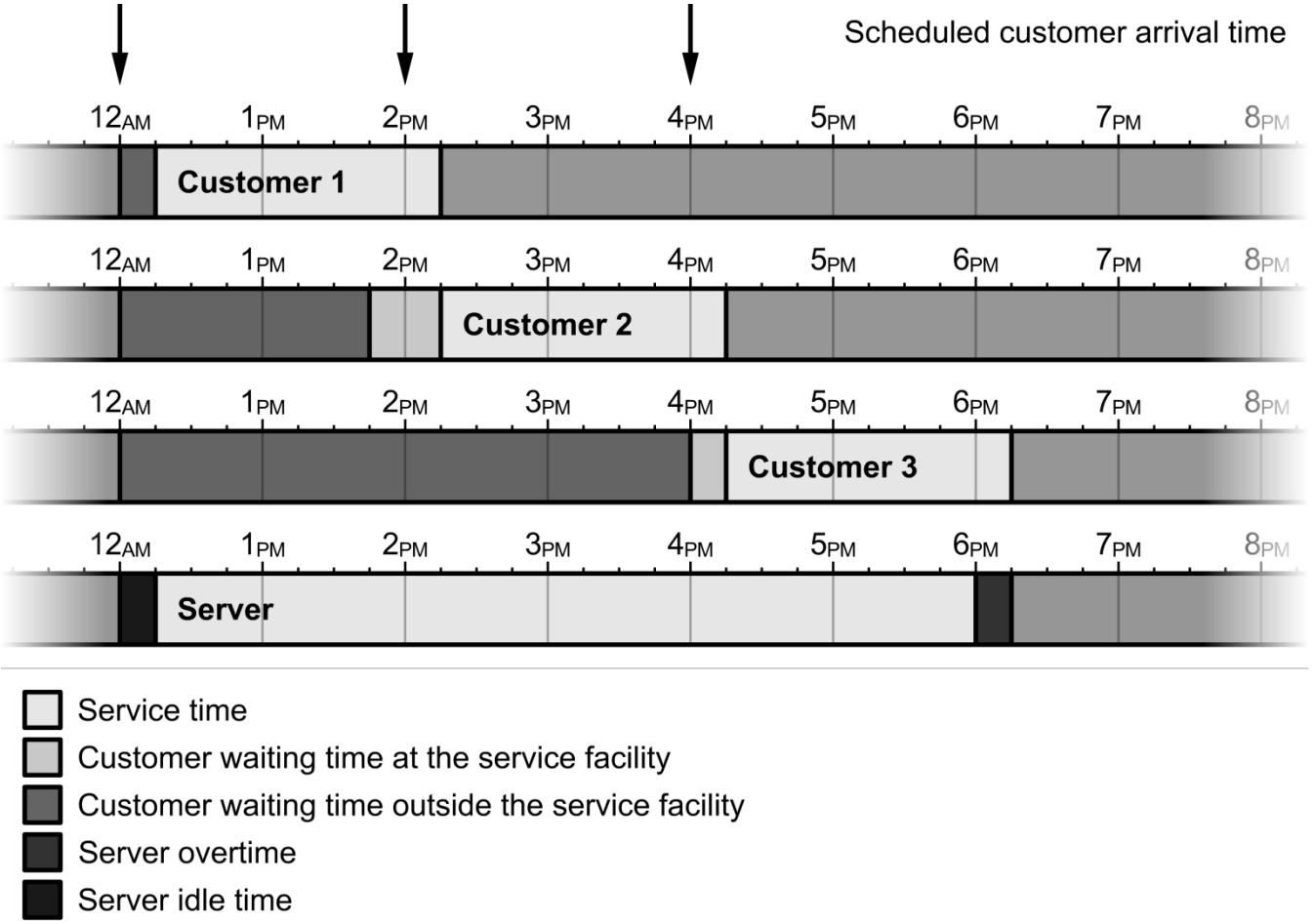
Var Interval ASR outperform if customer waiting time is the most critical performance criteria: thanks to the adapted arrival pace

Block ASR perform badly and should be avoided.

No-shows have the most severe impact on performance of the studied environmental parameters

Thank you

Example of service session
3 customers to schedule with 6h session

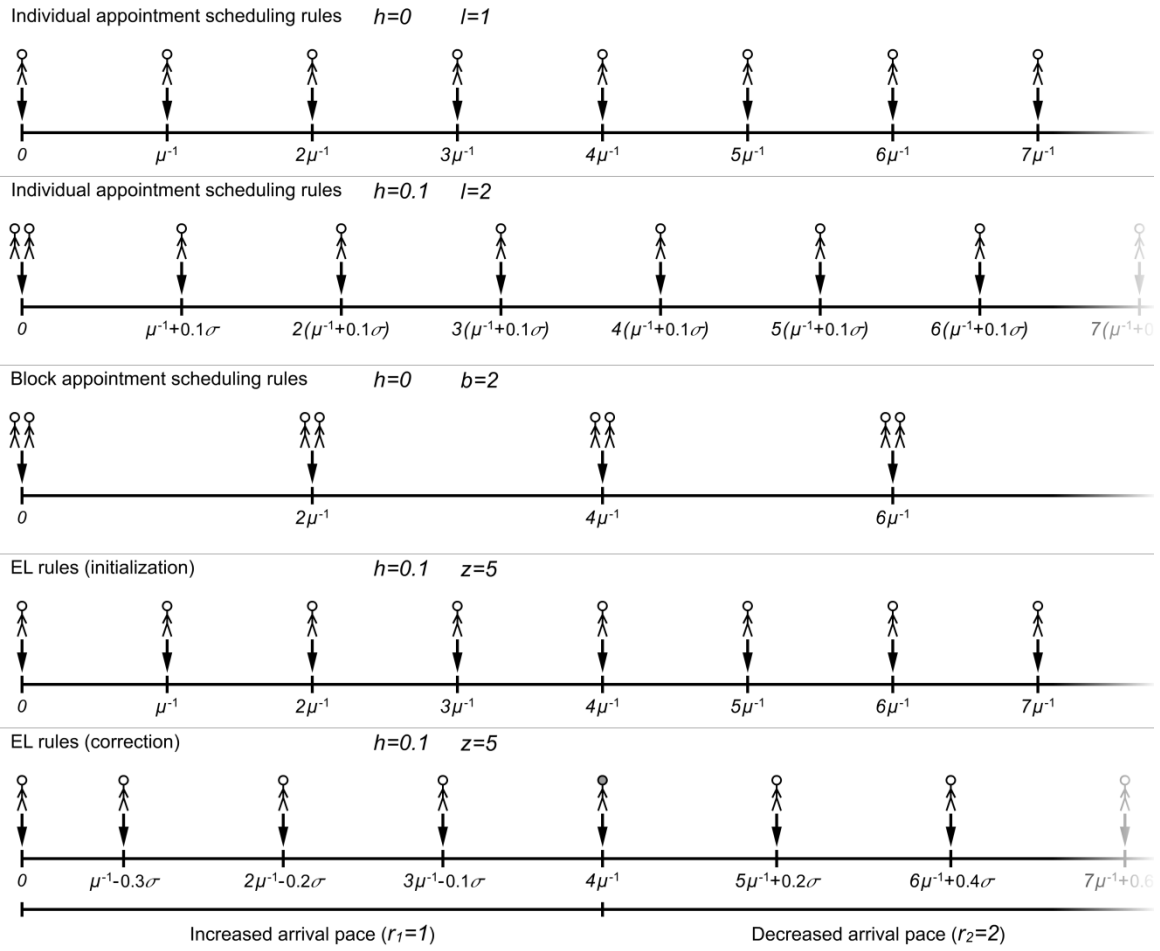


Different type of ASR

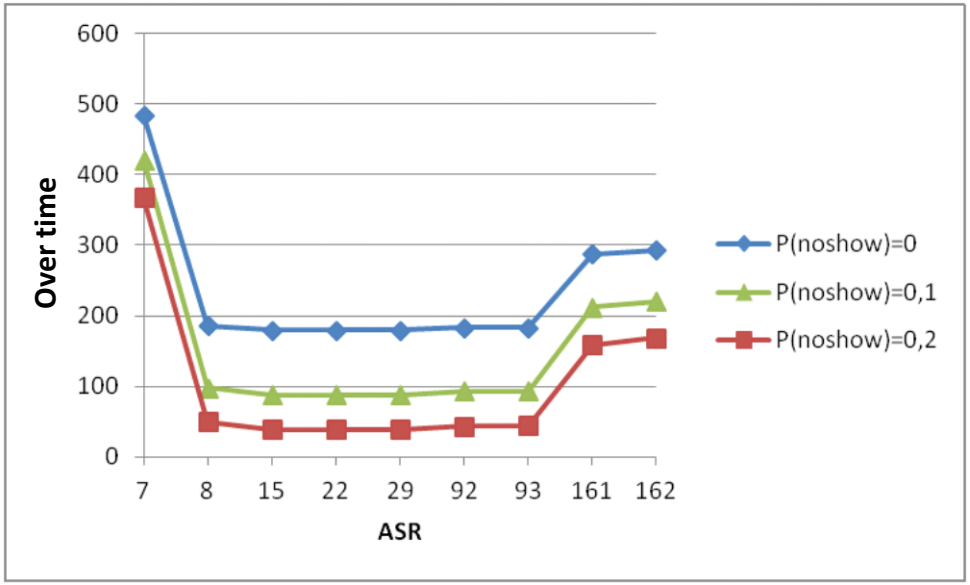
$$A_i = ia\mu^{-1}, \forall i < l$$
$$A_i = A_{i-1} + \mu^{-1} + h\sigma_i, \forall i \geq l$$

$$A_i = 0, \forall i < b$$
$$A_{nb} = A_{(n-1)b} + b\mu^{-1} + h\sqrt{b\sigma_{ni}},$$
$$\forall n: 1 \leq n < \frac{N}{b}$$
$$A_{nb+i} = A_{nb}, \forall i: 1 \leq i < b$$

1. $A_0 = 0, A_i = A_{i-1} + \mu^{-1}, \forall i < N$
2. $A_i = A_i - r_1(z-i)h\sigma_i, \forall i: 1 \leq 1 \leq z$
   $A_i = A_i - r_2(z-i)h\sigma_i, \forall i: z < 1 < N$



Which environmental factor influence the performance the most?



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