The relationship between the waiting crowd and the average service time

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Queueing theory deals with one of the most unpleasant experiences of life: waiting

Source picturehttp://stev ejbicknell.com/

Main practical question:
How many servers are needed?

Outline

1. Analytical approach (Kendall's notation)
2. Simulation approach with an example
3. Empirical data elicitation
4. Insights from the empirical data
5. Visualization of queuing situations

Kendall's Notation

▪ Interarrival times	Distribution function A
▪ Service times	Distribution function B
▪ Number of servers	m
▪ Capacity of the system	K
▪ Service discipline	D
→ Queuing system definition	A / B / m / K / D

Source picture: https://de.wikipedia.org

David George Kendall

Performance measures

- Number of waiting customers
- Waiting time of a customer

Customer-focused perspective

- Idle and busy time of a server
- Utilization of the server(s)

Server-focused perspective

Analytical solutions for several queuing systems

Analytic solution for …

- … M/D/1 queue in 1917 by Erlang.
- … M/D/k queue in 1920 by Erlang.
- … M/G/1 queue in 1930 by Pollaczek.
- … GI/M/k queue in 1953 by Kendall.
- … GI/G/1 queue in 1957 by Pollaczek.
- … G/G/1 queue in 1961 by Kingman.
- ….
- Solution for the following queuing systems: supositorio.com

Drawbacks of the analytical approach

- Analytic answers are only available for simpler generic cases.

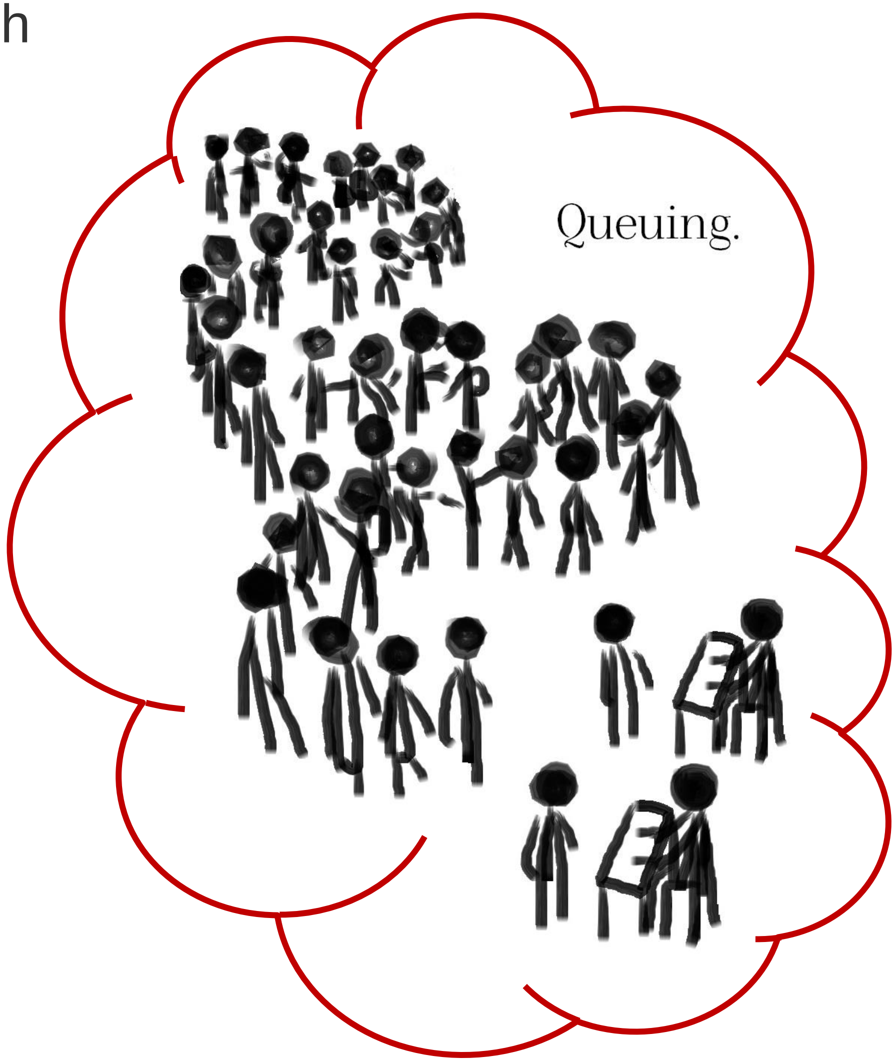
  → No analytic solution, if the queuing situation is quite complex (e.g. strong variation of the arrival rate).

- Analytic answers are idealized answers.

  → E.g. the physical layout of the queuing situation is not taken into account.

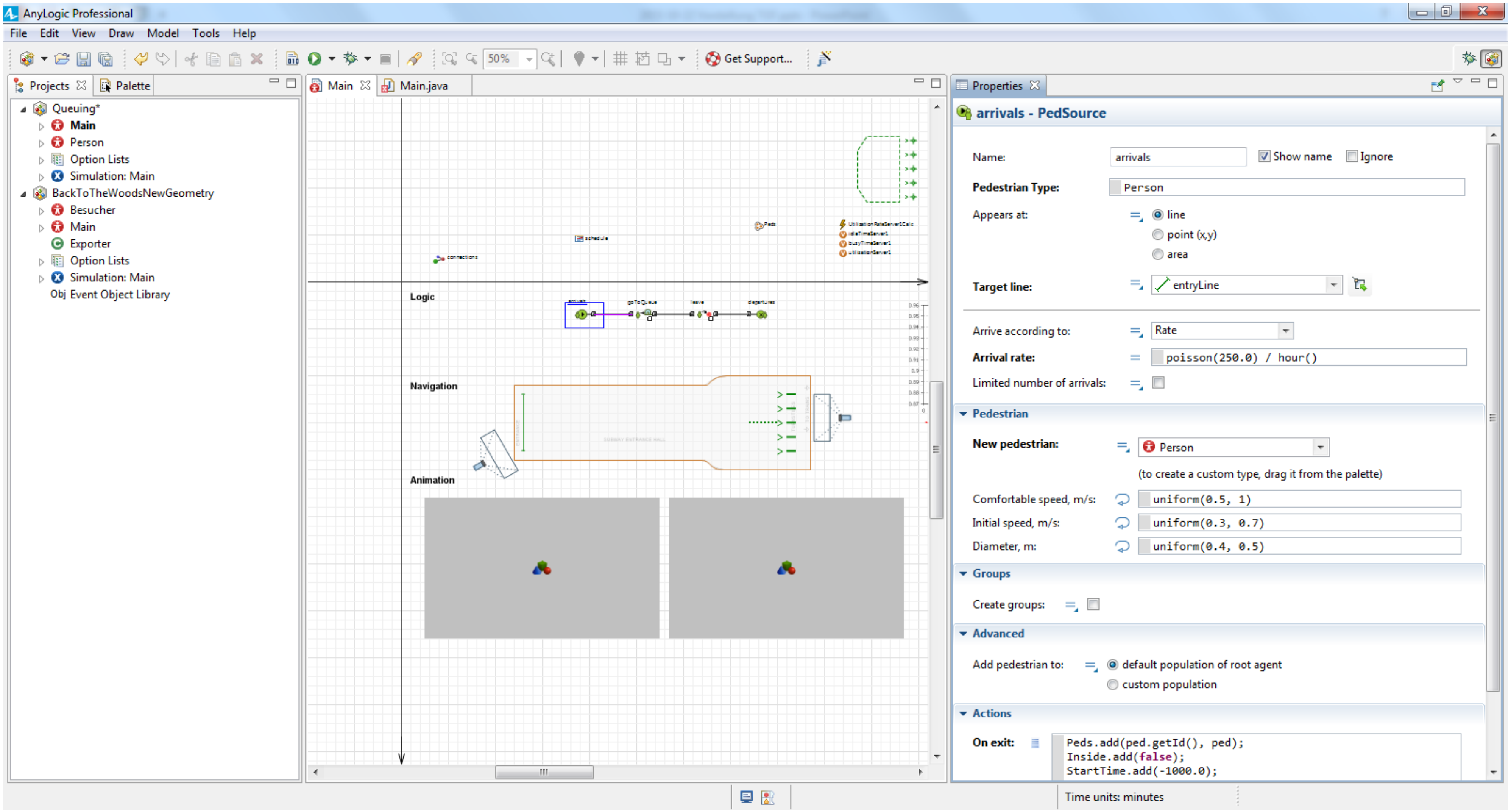
- Analytic answer are isolated answers.

  → The arrival rate and the service time are exogenous input.



Source picture: loseandfind.com

Simulation example with exogenous input (Java-based software Anylogic)



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Empirical data elicitation (based on post-evaluation of video data.)

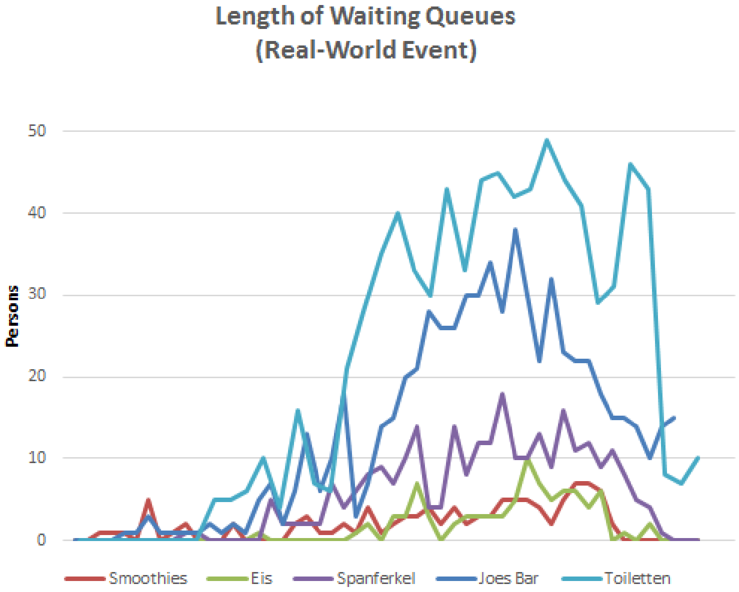
Service times / Average duration of use

Bar with beverages: 41,6 seconds

Food stand with self-made smoothies: 56,7 seconds

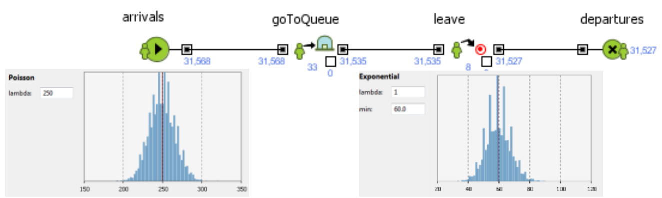
Food stand with piglings: 34,9 seconds

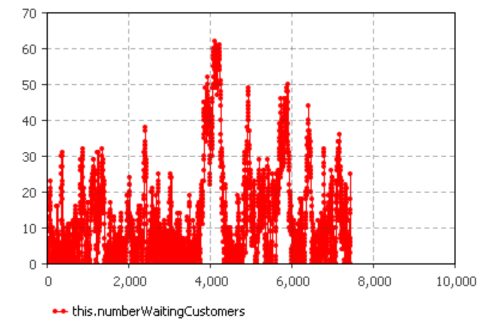
Mobile toilets: 59 seconds



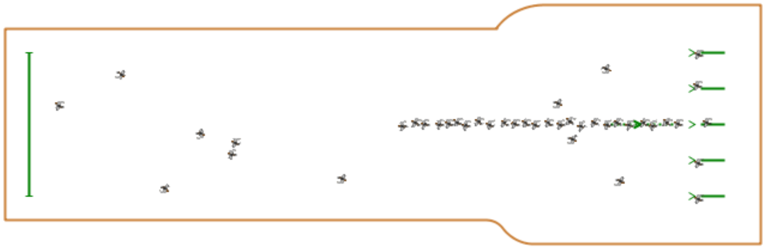
Simulation example with exogenous input

Logic

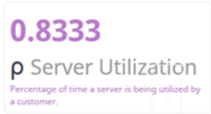


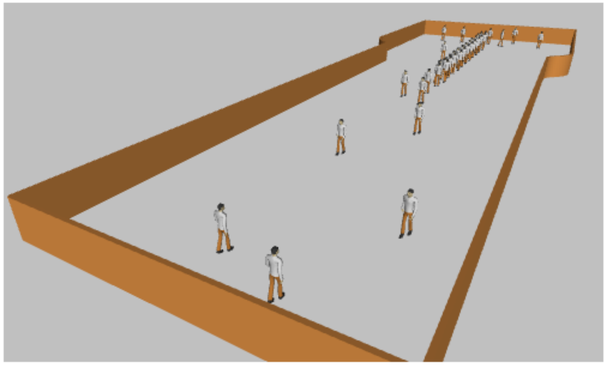


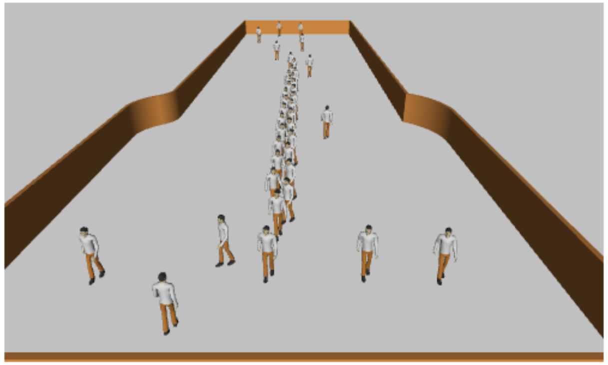
Navigation

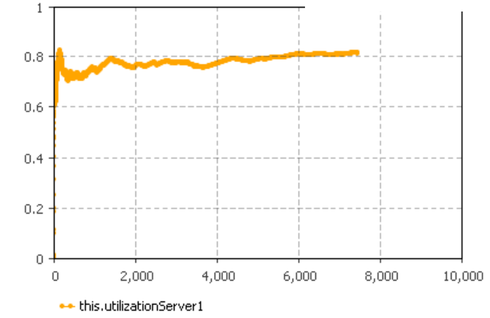


Animation









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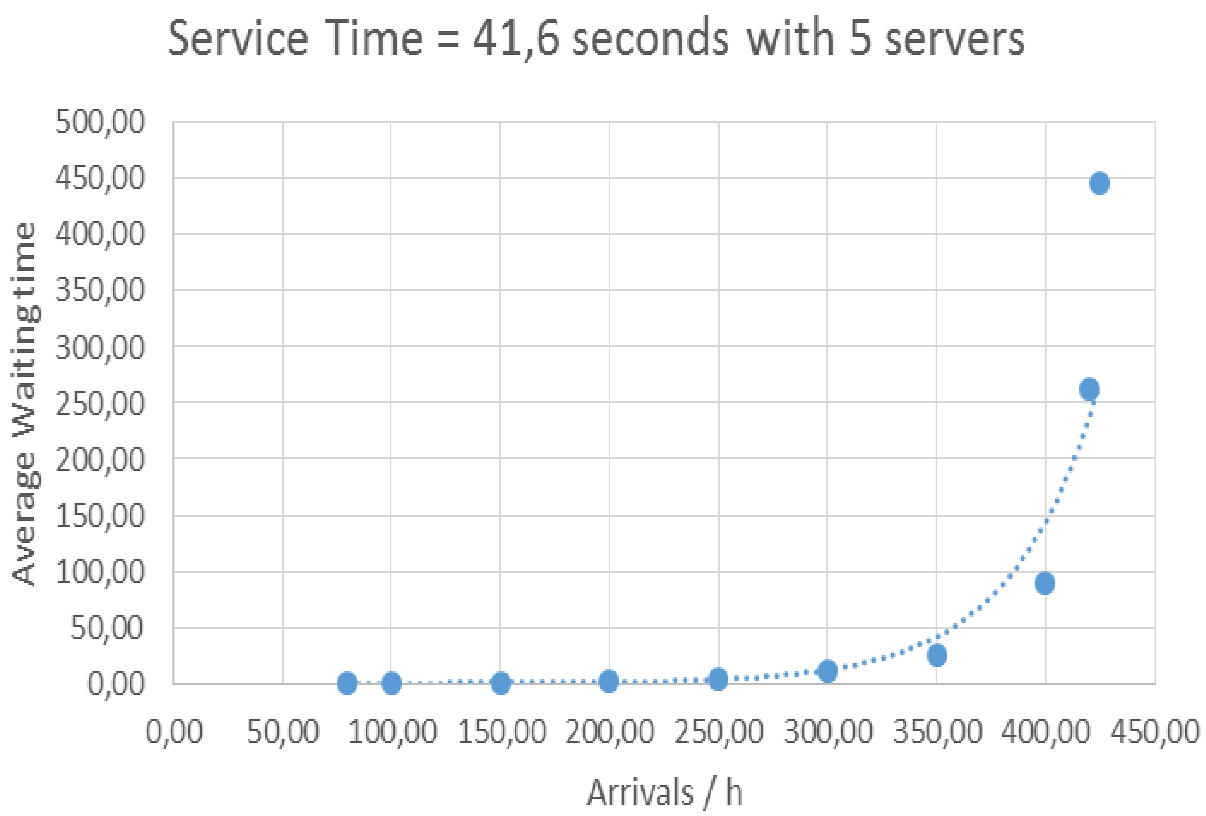
Bar Example: Varied arrival rate and fixed service time

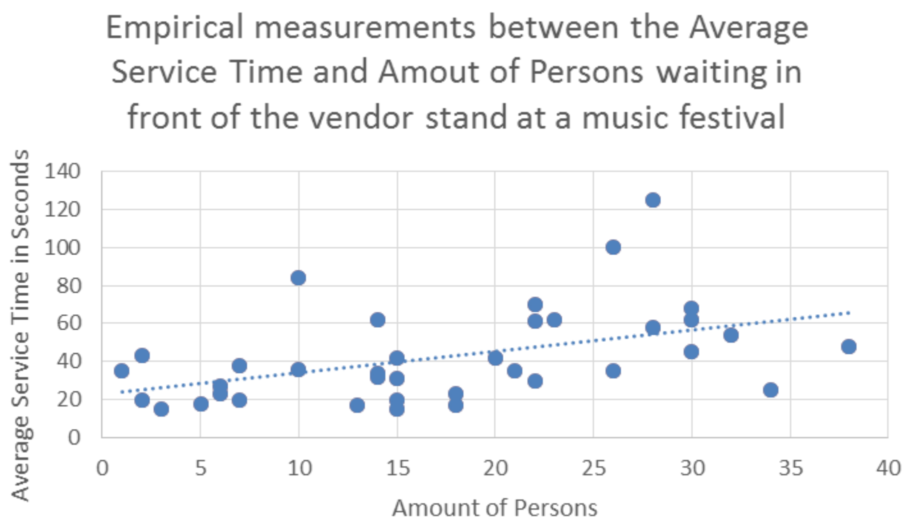


At some point we get very quickly to infinite waiting times.

Arrivals/hour = 350
→ 24 sec.
Arrivals/hour = 400
→ 90 sec.
Arrivals/hour = 450
→ ∞ (Infinite)

→ Tipping points in queuing
→ Self-regulation of the system to avoid going beyond the tipping points

Interesting finding from the empirical data elicitation



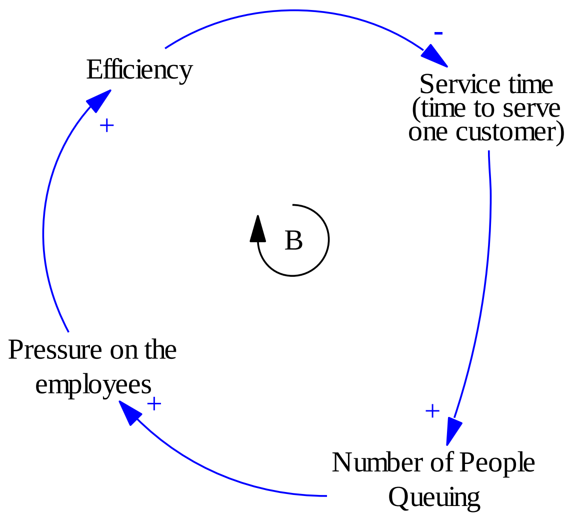
Counterintuitive finding

Increase of queue size leads to an increase of the average service time.

Assumption

Increase of queuing size leads to an increase in the size of orders (grouping and postponment effect) and can not be compensated by an increase of labor efficiency.

Dynamic feedback in the real-world prevents the system to go beyond the tipping point



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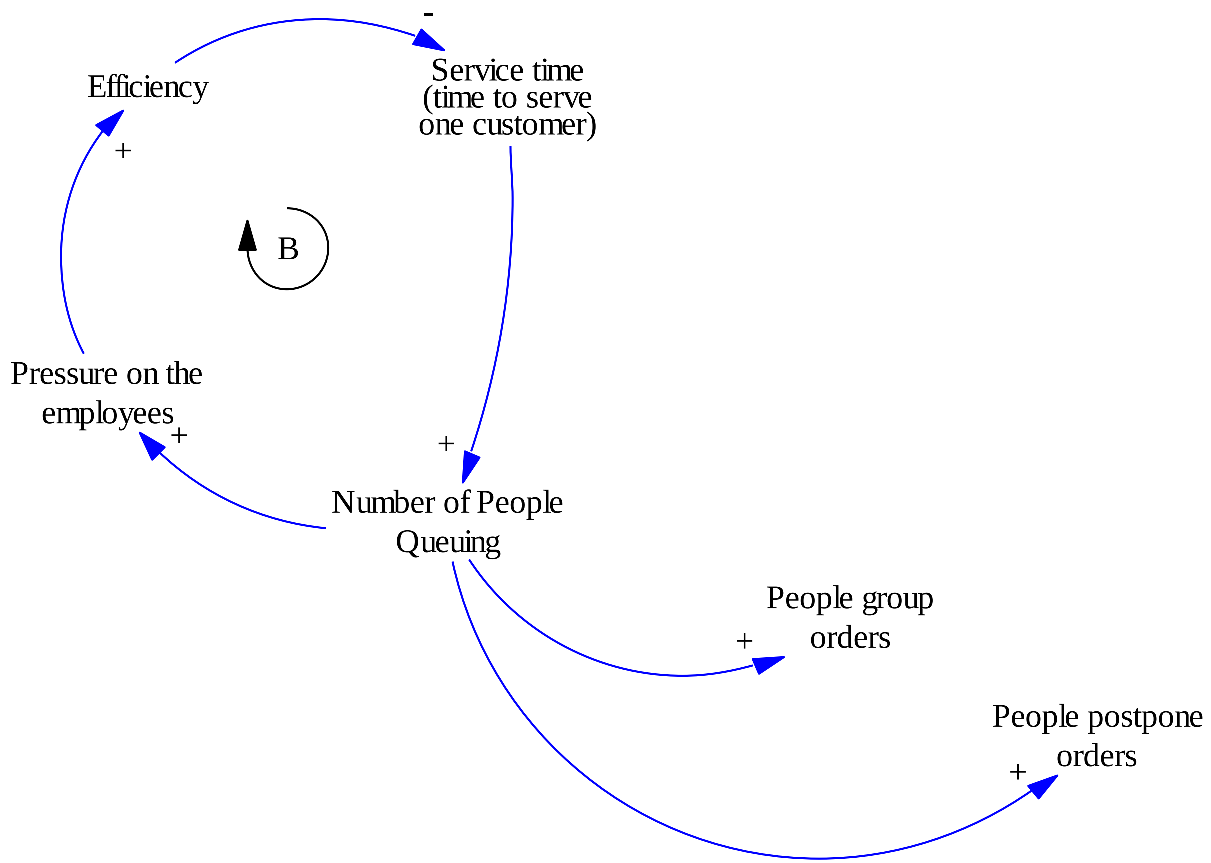
Dynamic feedback in the real-world prevents the system to go beyond the tipping point



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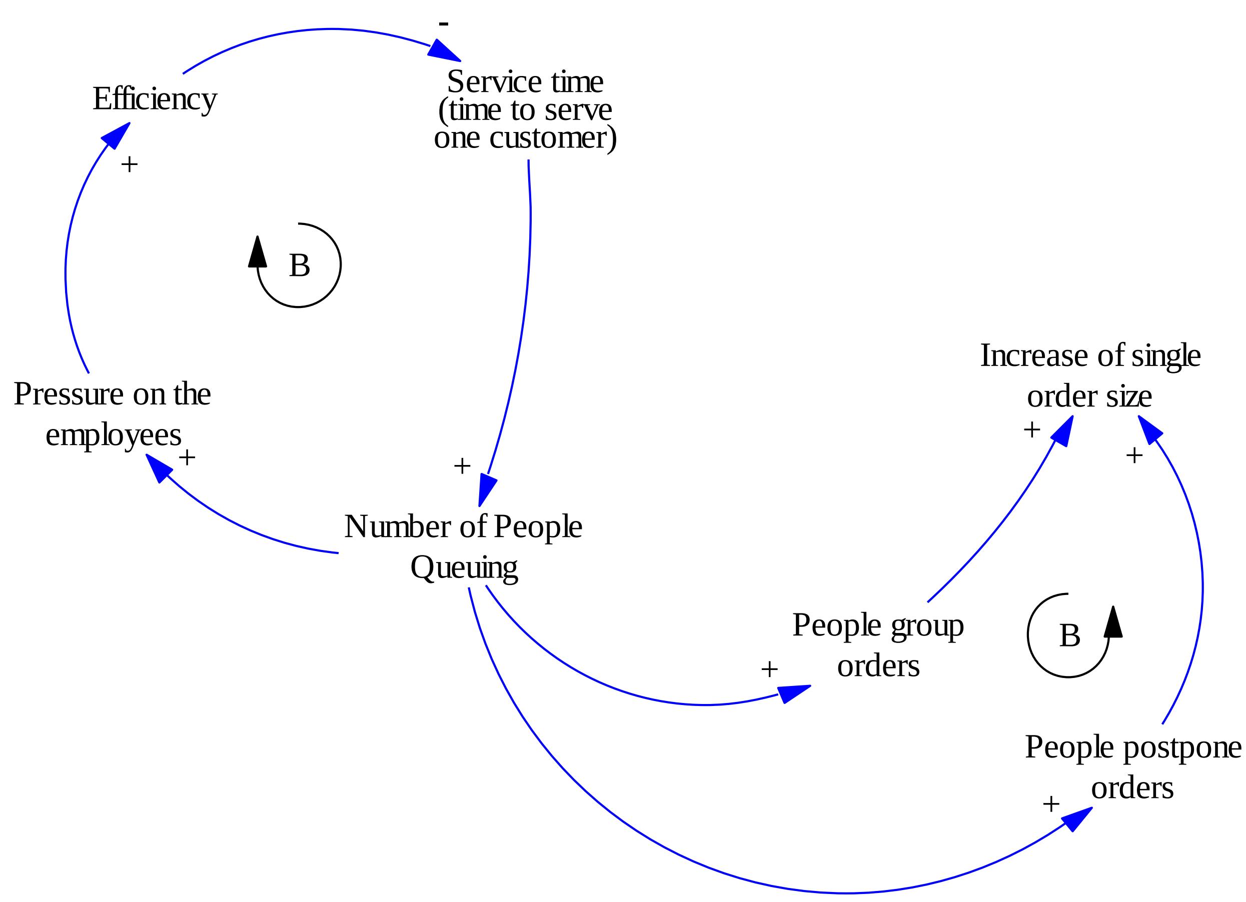

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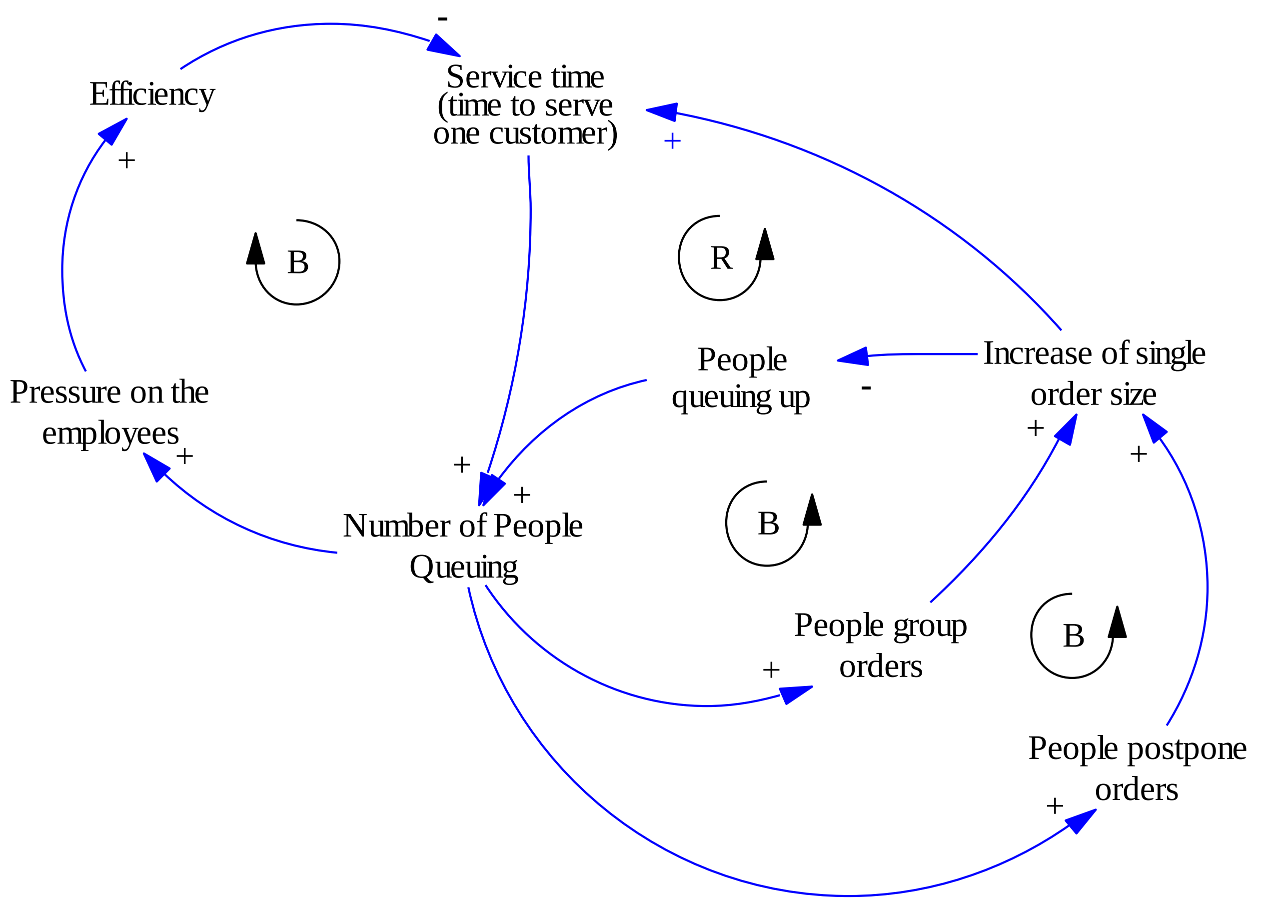

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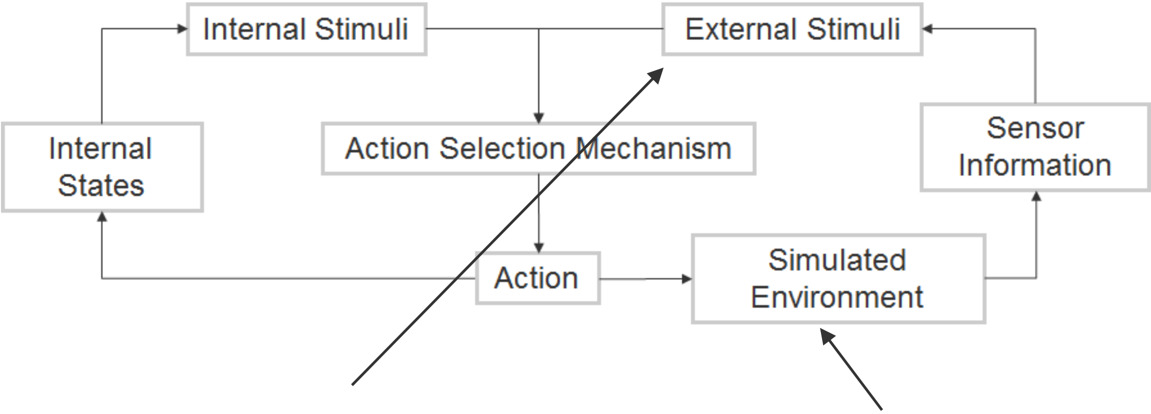
Incorporating dynamic feedback in the action selection layer of the simulation



Action Selection Mechanism (AAM) for the dynamic decision-making of the virtual humans.

getQueueLength()

→ Multiplier affecting action selection

→ Incorporation of postponement effect

serviceTimeAdjustment(int queueLength)

→ Incorporation of the service time increase

Queuing situations in pedestrian simulation

You can use our post-visualization software with your own data: www.bit.ly/1Nzxduq

(https://www.cms.bgu.tum.de/de/forschung/projekte/oip/31-forschung/projekte/463-pedvis)

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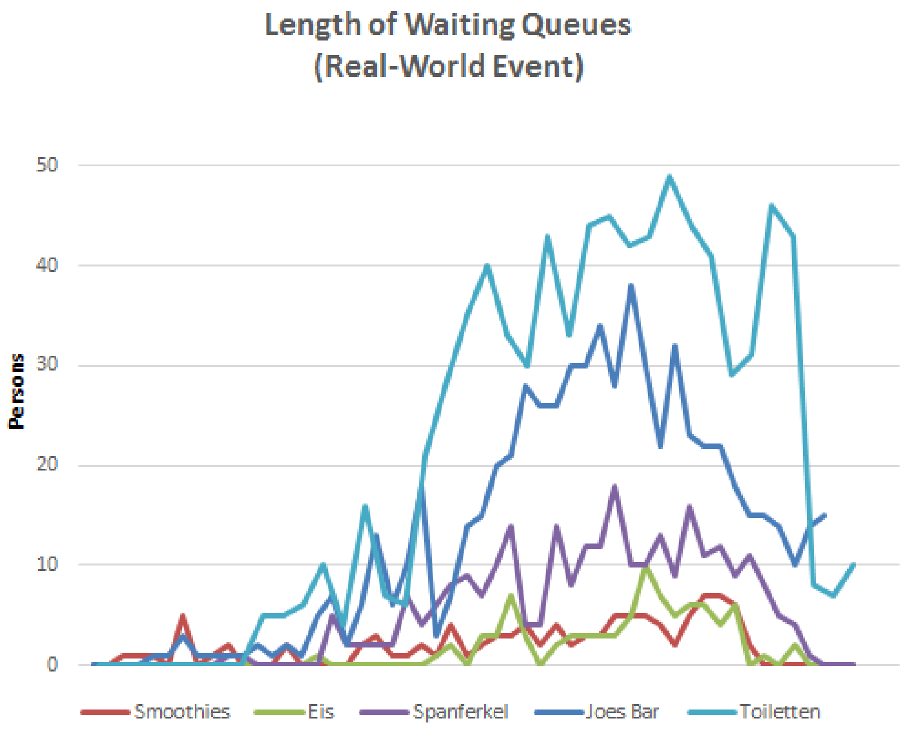
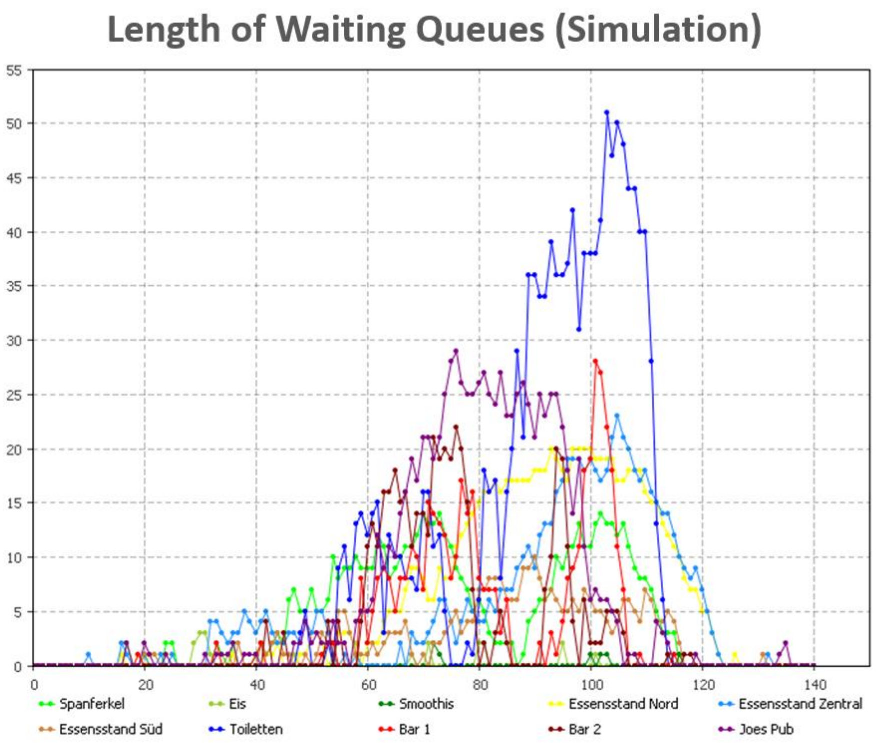
Comparison between the simulated microworld and the real-world data





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Conclusion

- Queuing behavior is of fundamental importance in pedestrian and traffic simulation, because queues define the bottlenecks of your system.
- Generating benchmarks with simulation is often easier and more accurate than coming up with an analytic solution, because boundary conditions can be endogenized.
- Feedback from the length of the queue on the people that start queuing up is essential, as you otherwise may end up several times in situation beyond the tipping point (unrealistic).

Picture source: dailymail.co.uk

Thank you for your attention!