



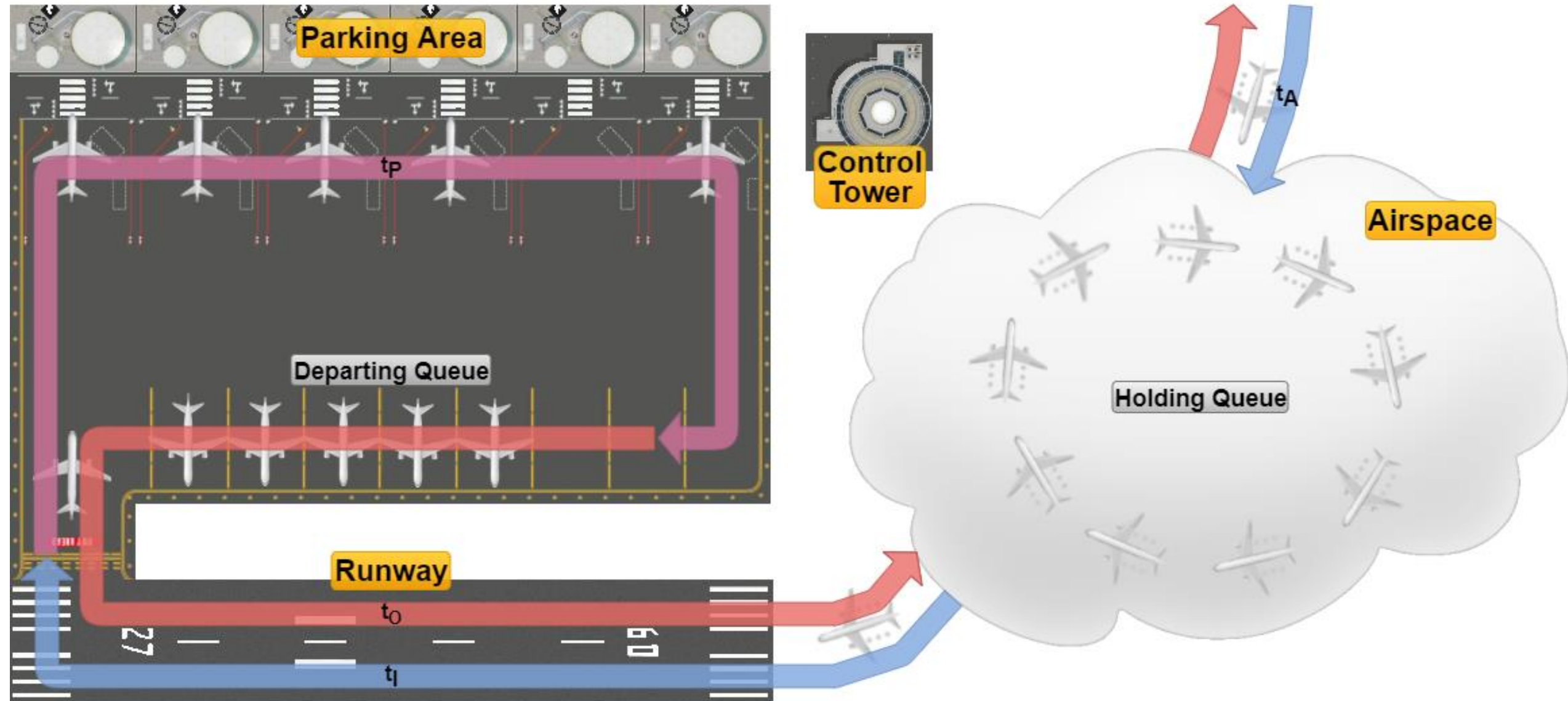
UNIVERSITÀ DI PISA

Performance Evaluation of Computer Systems and Networks

Control Tower System Analysis

Nicola Barsanti, Riccardo Bertini, Luigi Treccozzi

System Model



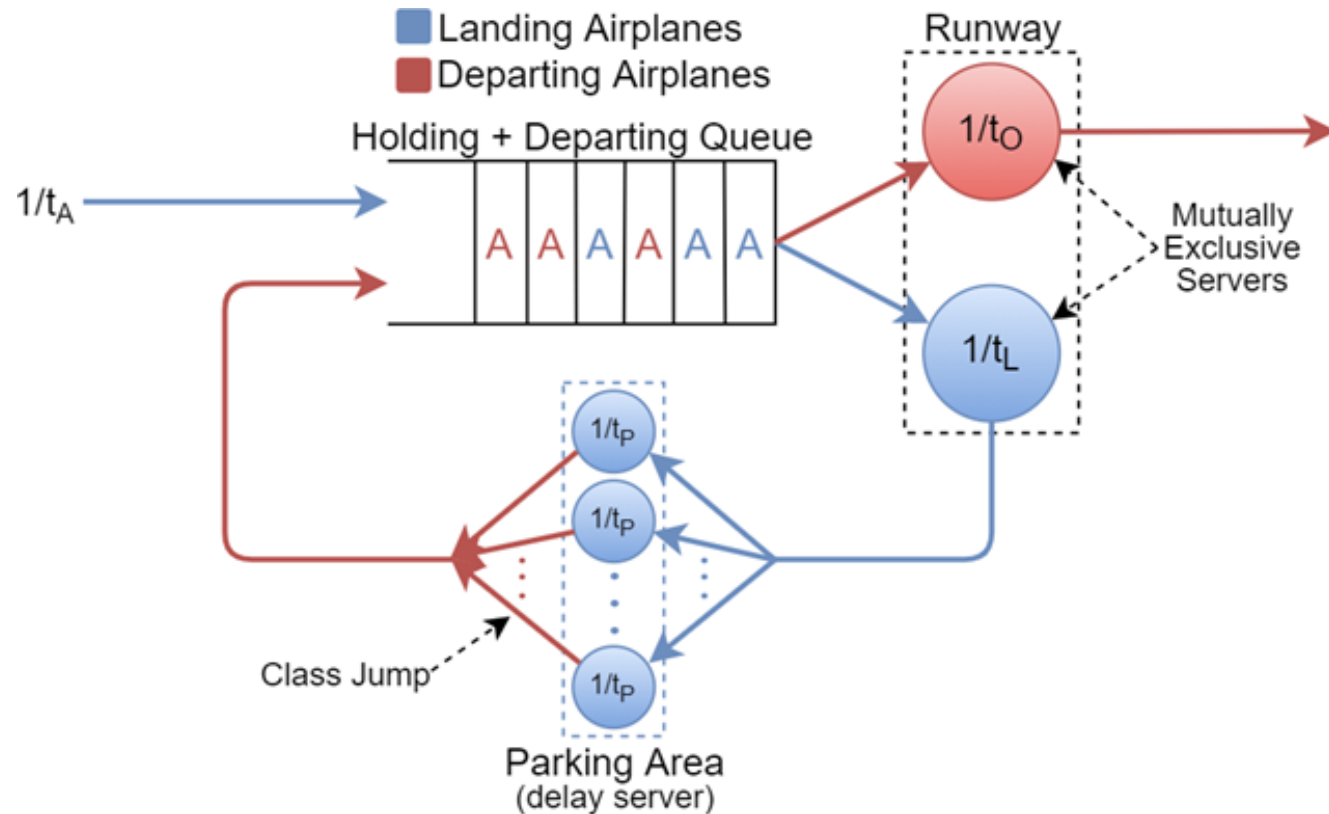
Working Hypotheses

- 1) Analyse in both deterministic and exponential regimes.
- 2) Airplanes waiting for landing have an infinite fuel supply.
- 3) The parking area has an infinite airplane capacity.

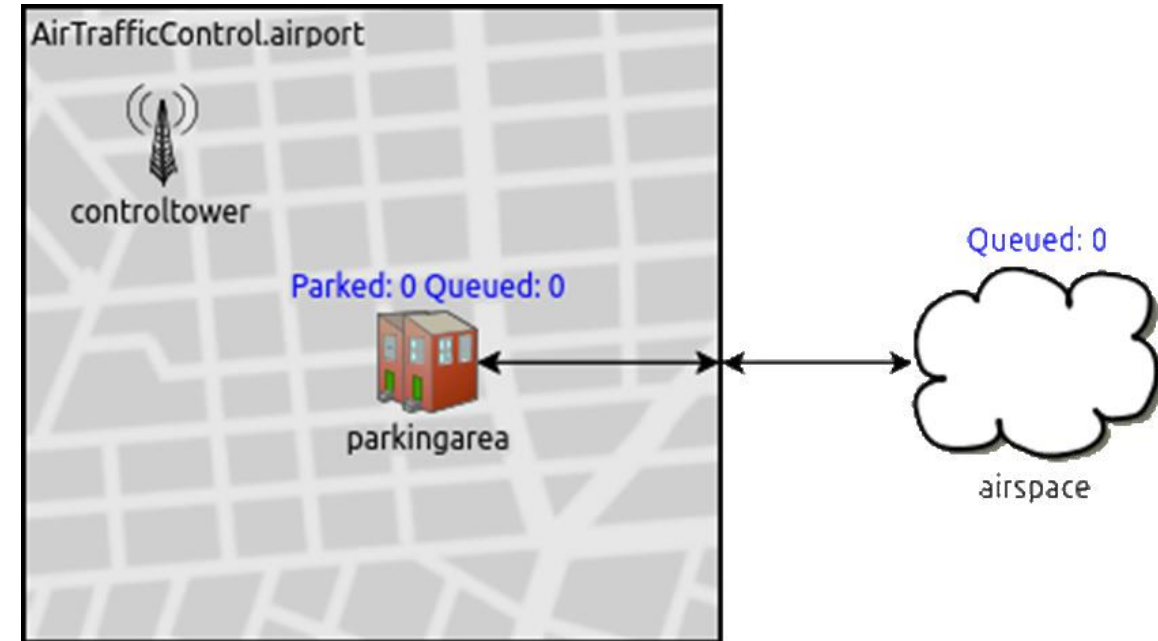
Additional Hypotheses

- 4) System analysis starts from its empty state.
- 5) t_p starts when leaving the runway, ends when enqueueing for take-off.
- 6) In case of conflicts, the airplane waiting for landing has the priority.
- 7) No real-world delays or other factors are taken into account.

QT Equivalent Model



Simulation Model



- Queues merged in a single logical queue
- Control Tower has no correspondence
- Steady-state equations can't be derived
- Three simple modules
- The runway is a connection
- Control tower is a logical module

System Statistics

- The number of airplanes waiting in both queues (*Holding Queue Size* and *Depart Queue Size*)
- The airplanes' waiting times in both queues (*Holding Queue Waiting Time* and *Depart Queue Waiting Time*)
- The number of parked airplanes (*Parked Planes*)
- The system total response time (*Airport Response Time*)

System Stability Analysis

Stability Condition: $t_A > t_L + t_O \Rightarrow \lambda_A < \frac{\mu_L \mu_O}{\mu_L + \mu_O}$

Equivalent Service Rate: $\mu_E = \frac{\mu_L \mu_O}{\mu_L + \mu_O} < \mu_L, \mu_O \quad \mu_L, \mu_O > 0$

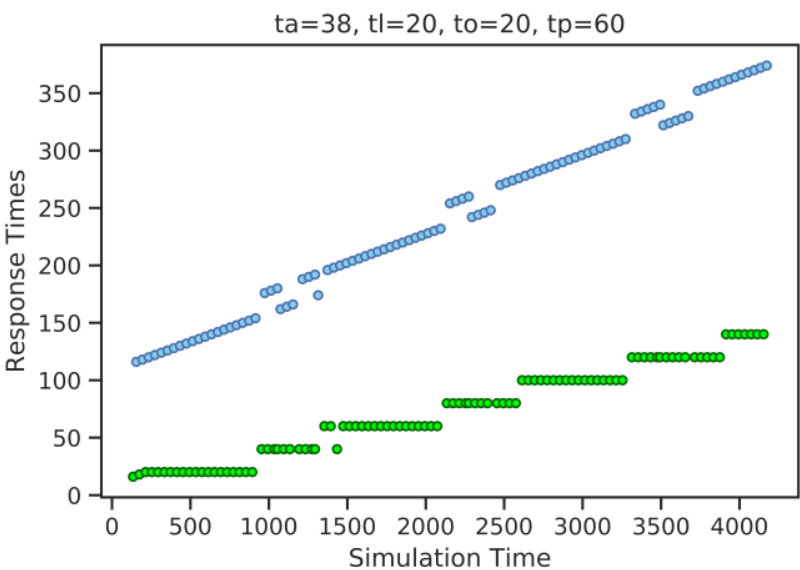
System Utilization Factor: $\rho = \frac{\lambda_A}{\mu_E} = \frac{\lambda_A (\mu_L + \mu_O)}{\mu_L \mu_O} = \frac{t_L + t_O}{t_A}$

- Airport Response Time samples
- Queues Waiting Time samples
- Queues Waiting Time Median
- Airport Response Time Median

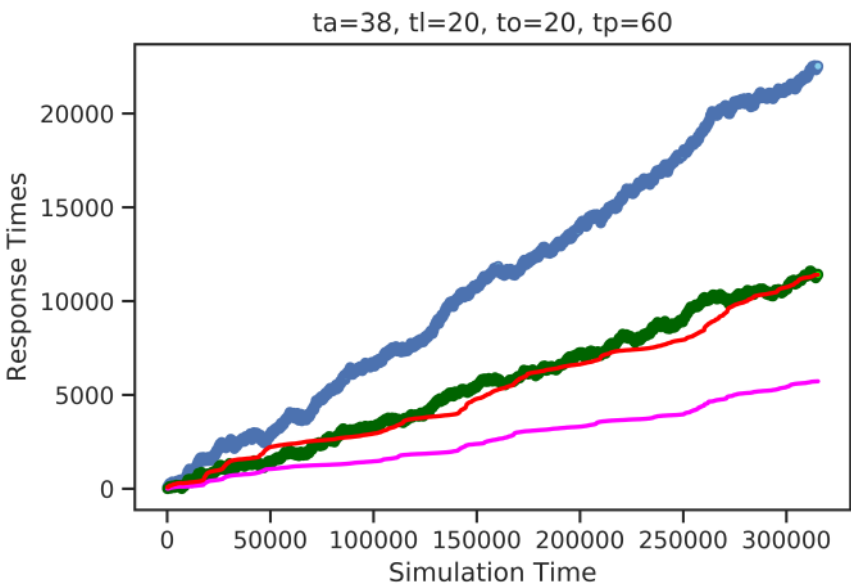
System Instability

$$(t_A < t_L + t_o)$$

Deterministic

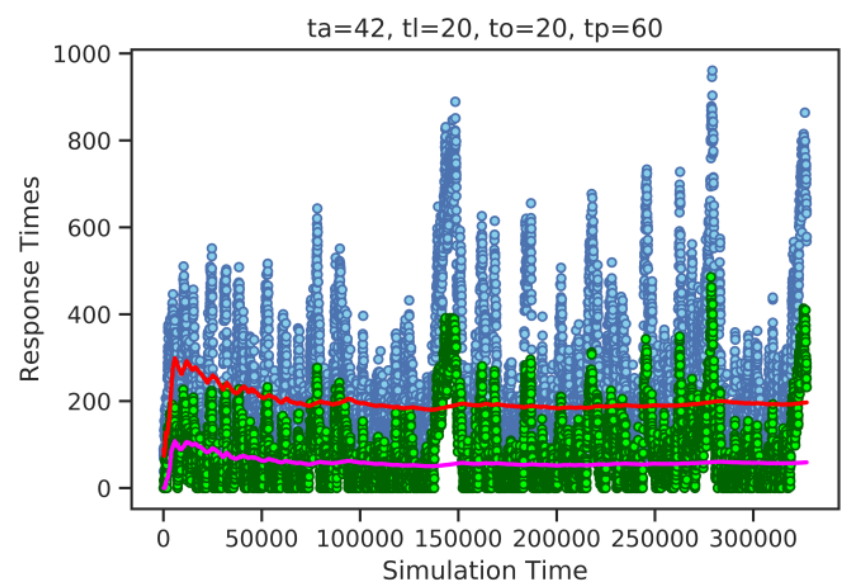
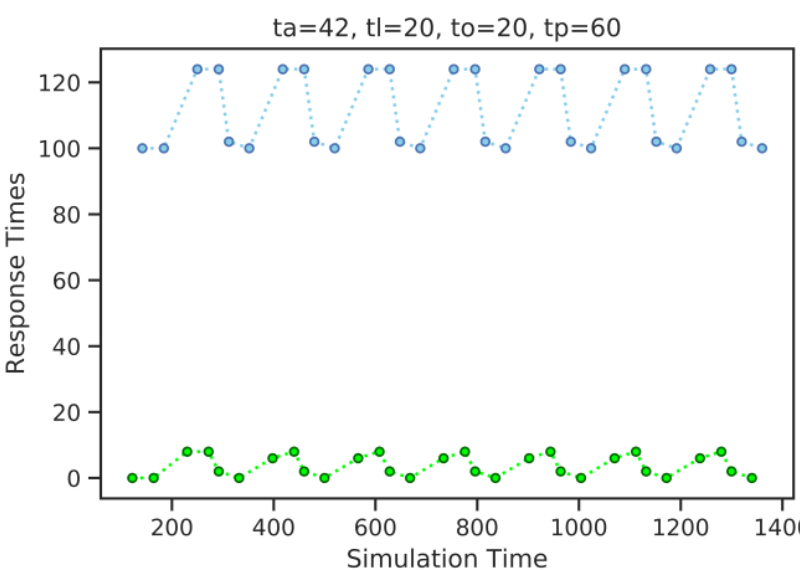


Exponential



System Stability

$$(t_A > t_L + t_o)$$

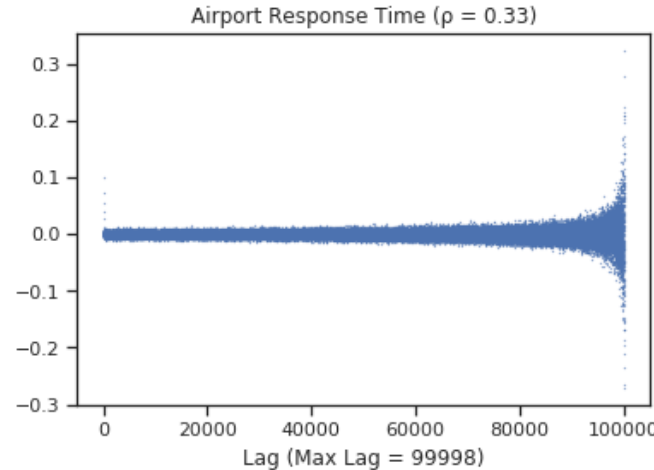


Subsampling and Confidence Levels

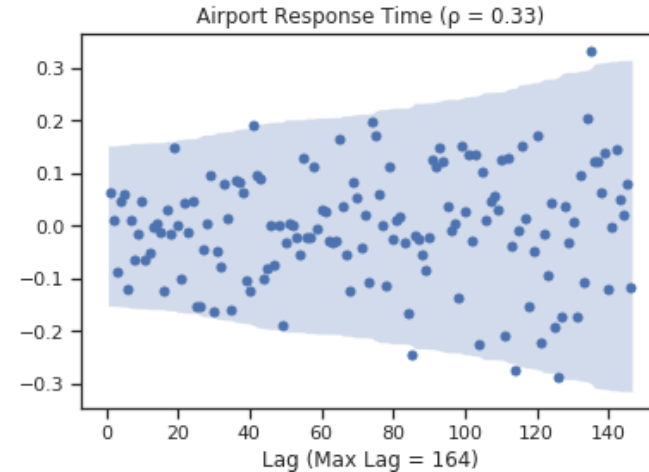
Statistics autocorrelation dependent on the utilization factor ρ

Low Utilization
($\rho = 0.33$)

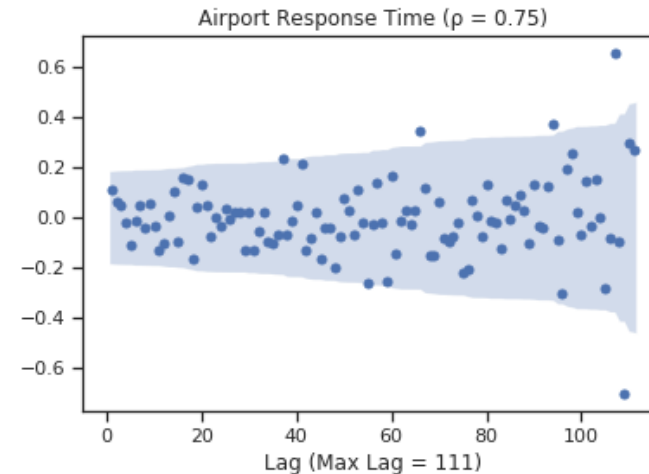
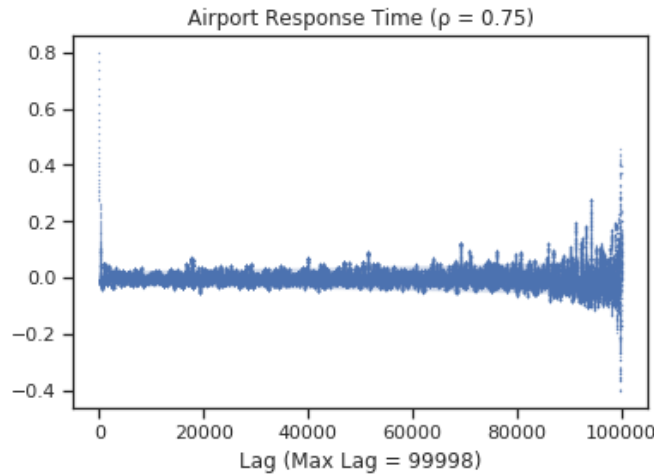
Before Subsampling



After Subsampling



High Utilization
($\rho = 0.75$)



Confidence intervals taken with a confidence level of 95% ($\alpha = 0.05$)

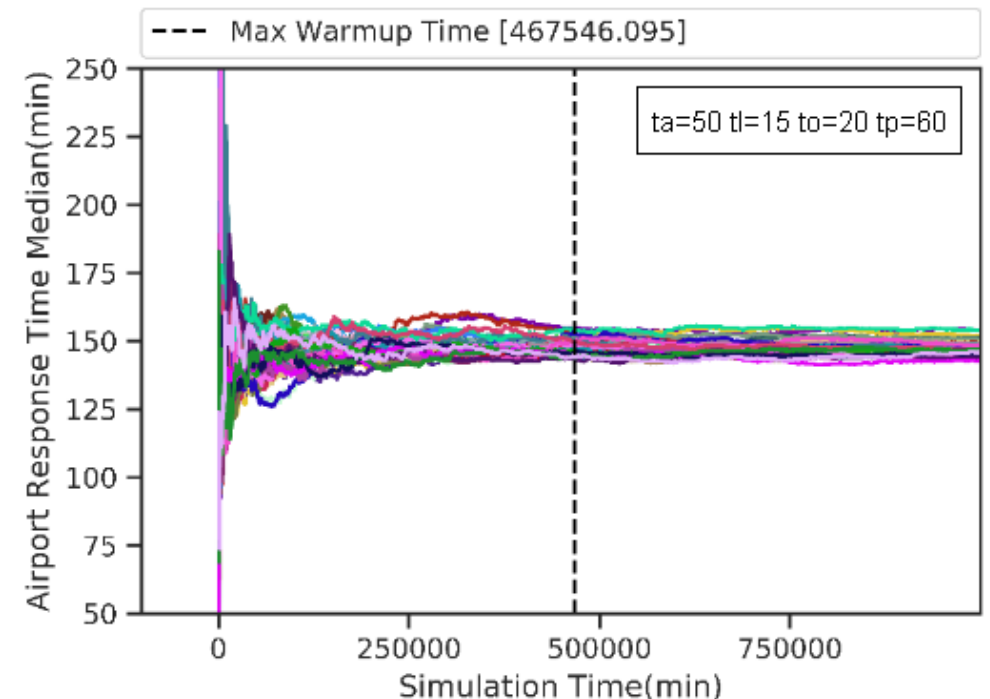
Warm-up Time Study

System warm-up time corresponds to the time required by the mean throughput of airplanes on the feedback loop (*Parking Area*) to stabilize.

Deterministic Warm-up Time:

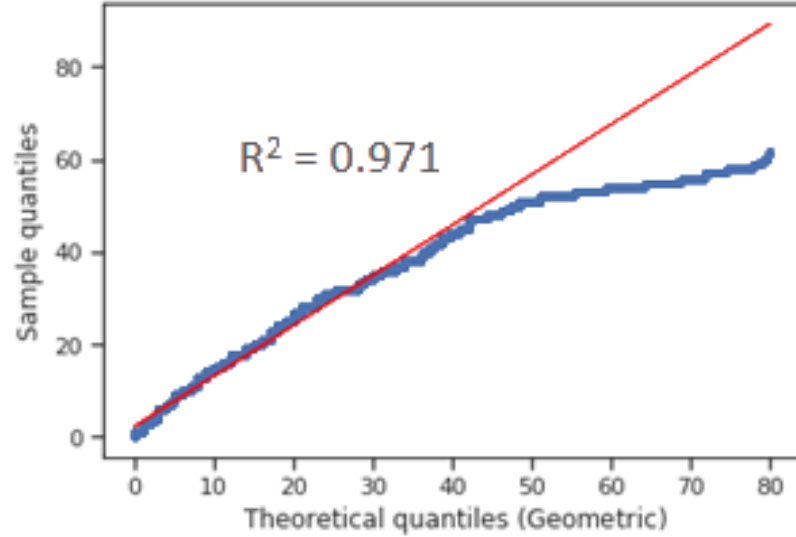
$$t_{WA} = t_A + t_L + t_P$$

Exponential Warm-up Time:

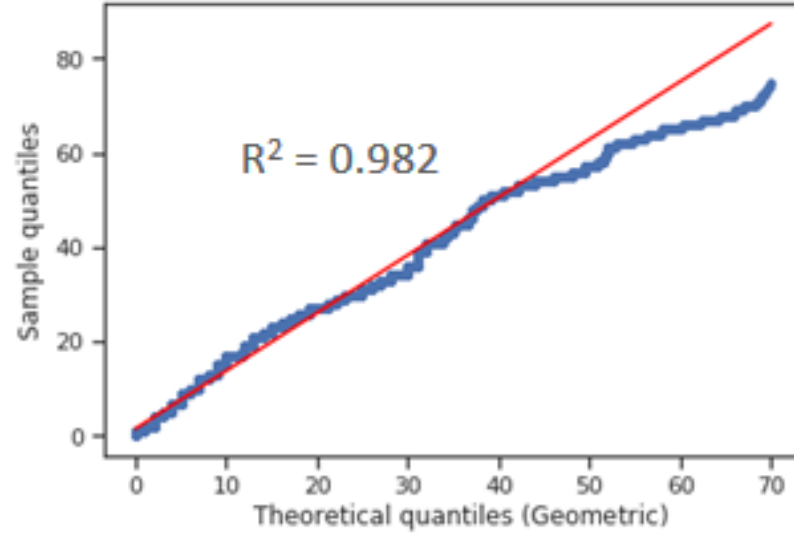


Statistics Distributions Fitting

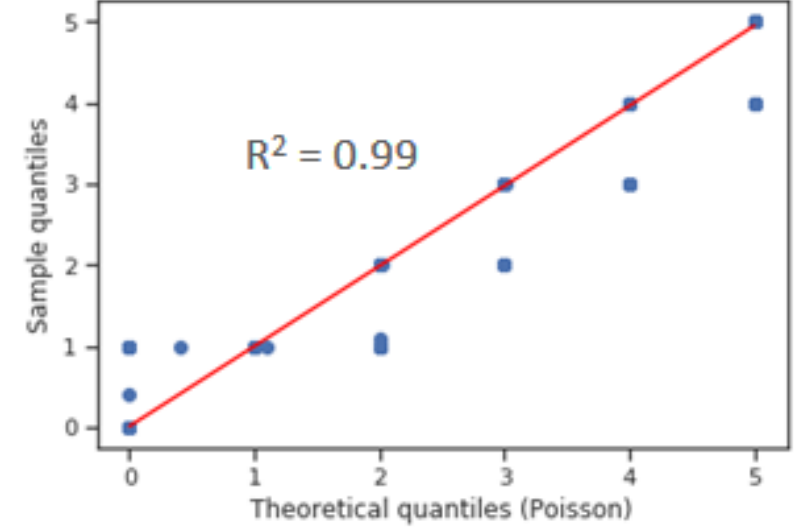
QQPlot - Holding Queue Size



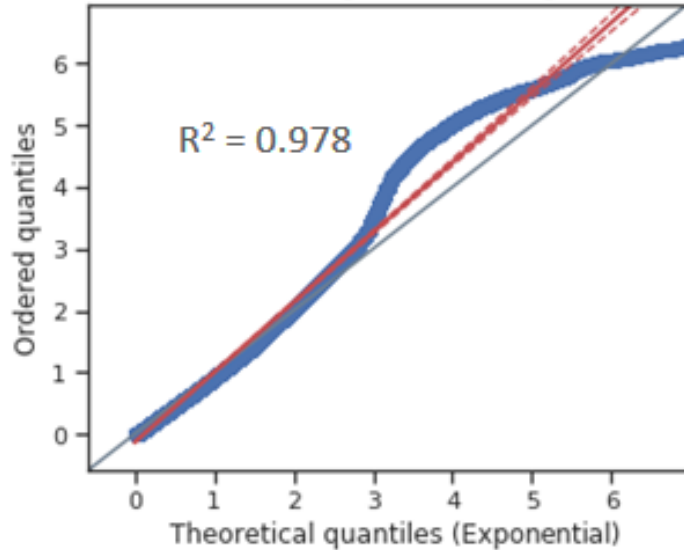
QQPlot - Depart Queue Size



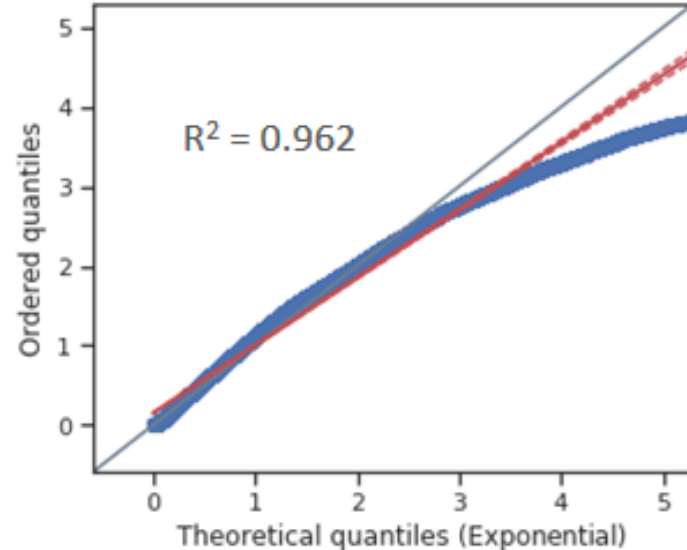
QQPlot - Parked Planes



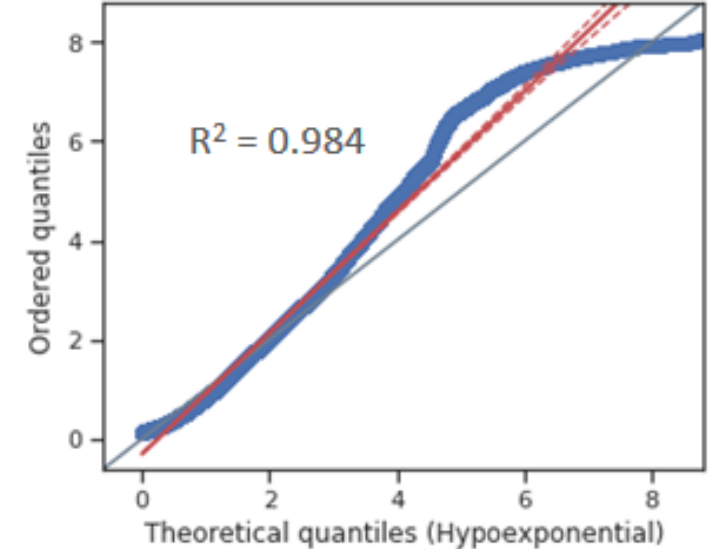
QQPlot - Holding Queue Waiting Time



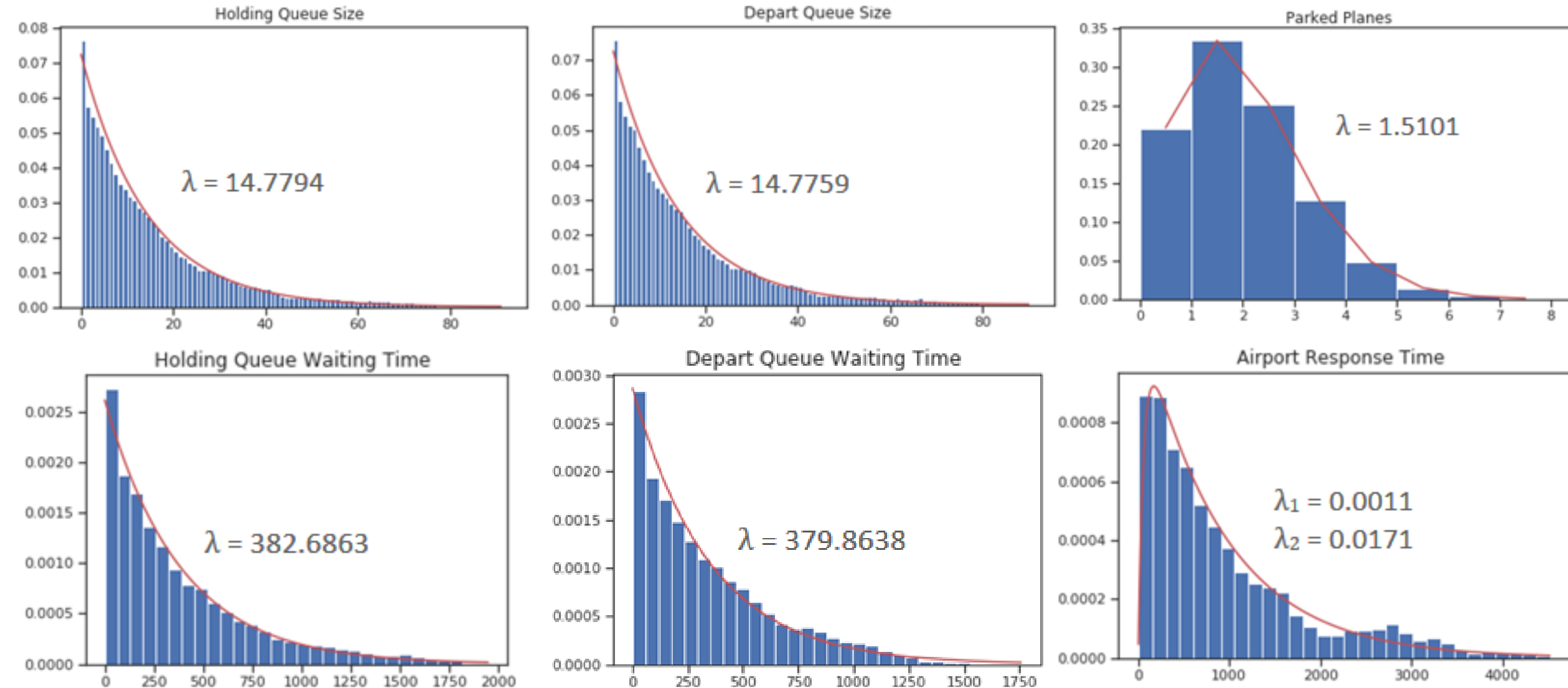
QQPlot - Depart Queue Waiting Time



QQPlot - Airport Response Time



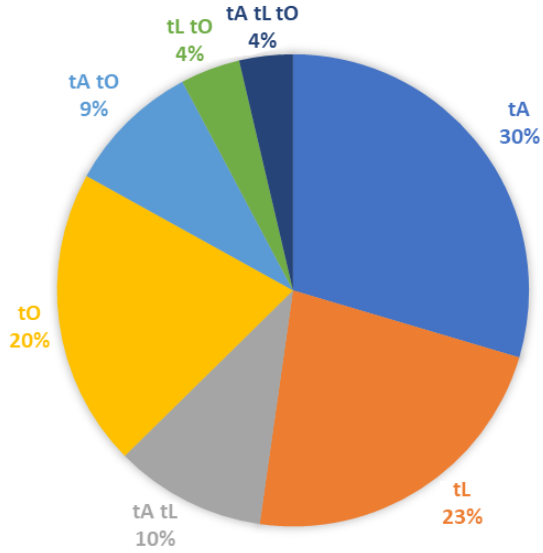
Maximum Likelihood Estimators



Both queues share the same distributions with the same parameters

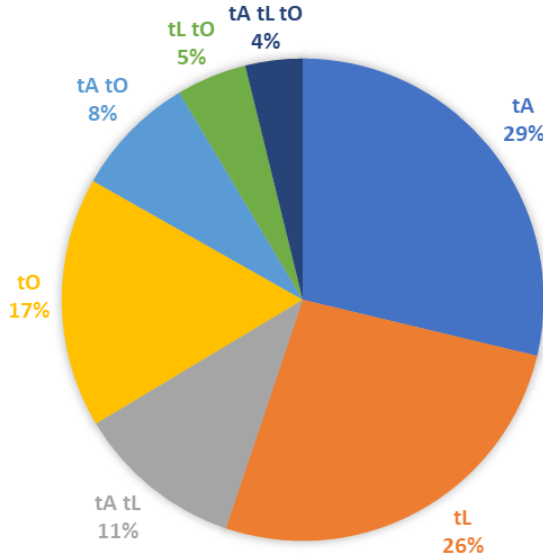
2^{kr} Factorial Analysis

Holding Queue Size



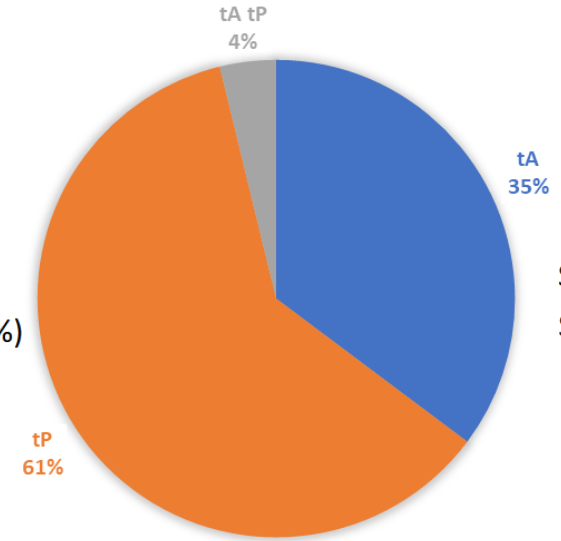
SST = $4.59 \cdot 10^3$
SSE = 0.901 (0.02%)

Depart Queue Size



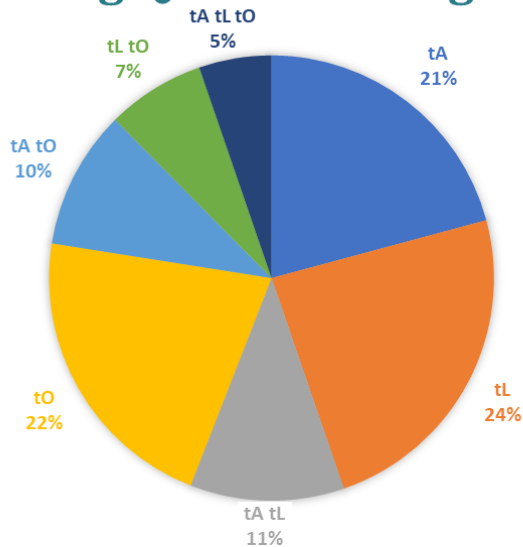
SST = $4.63 \cdot 10^3$
SSE = 0.905 (0.02%)

Parked Planes



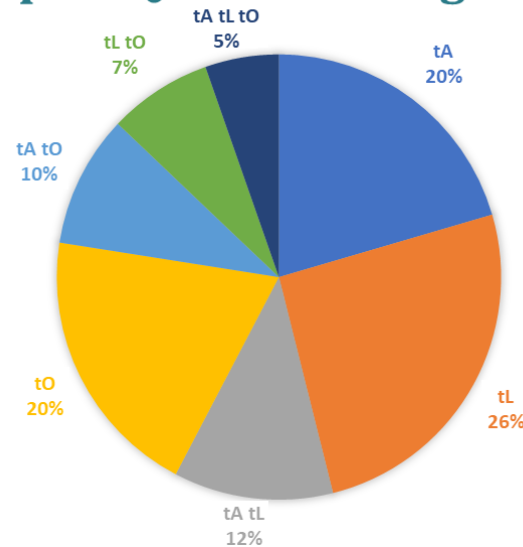
SST = $2.1 \cdot 10^3$
SSE = 0.0373 (0.00%)

Holding Queue Waiting Time



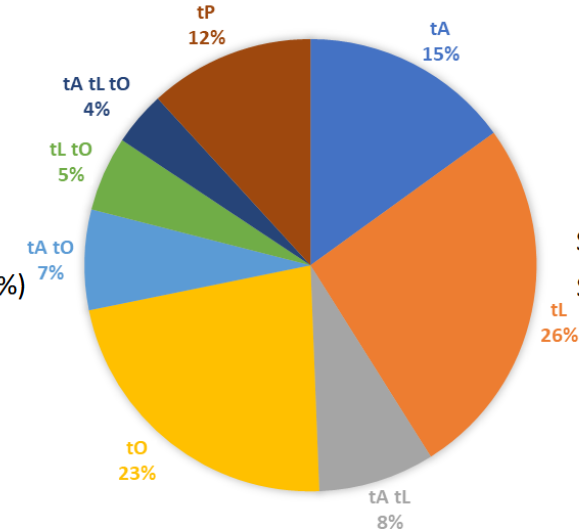
SST = $1.12 \cdot 10^7$
SSE = $2.25 \cdot 10^3$ (0.02%)

Depart Queue Waiting Time



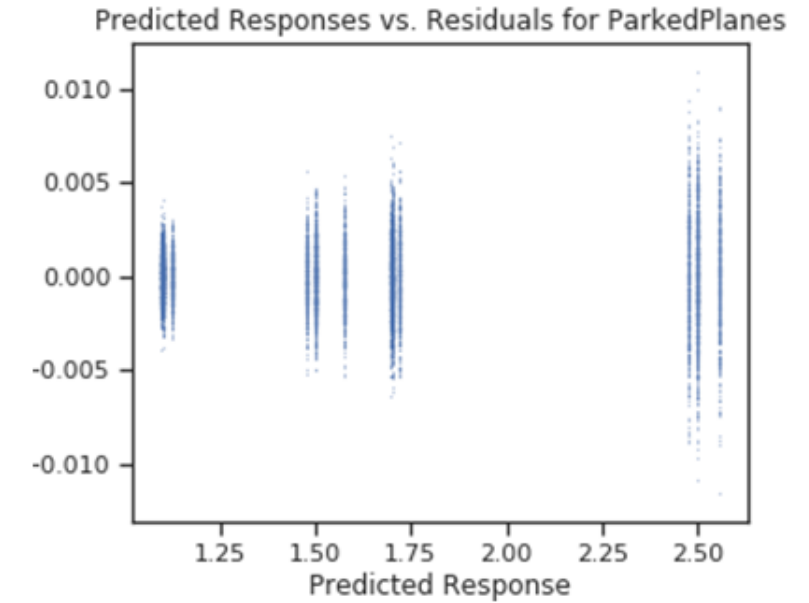
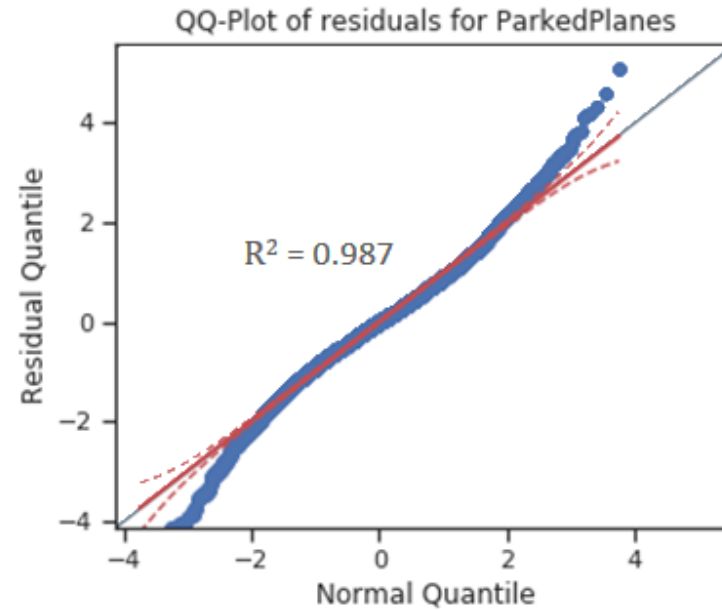
SST = $1.12 \cdot 10^7$
SSE = $2.25 \cdot 10^3$ (0.02%)

Airport Response Time

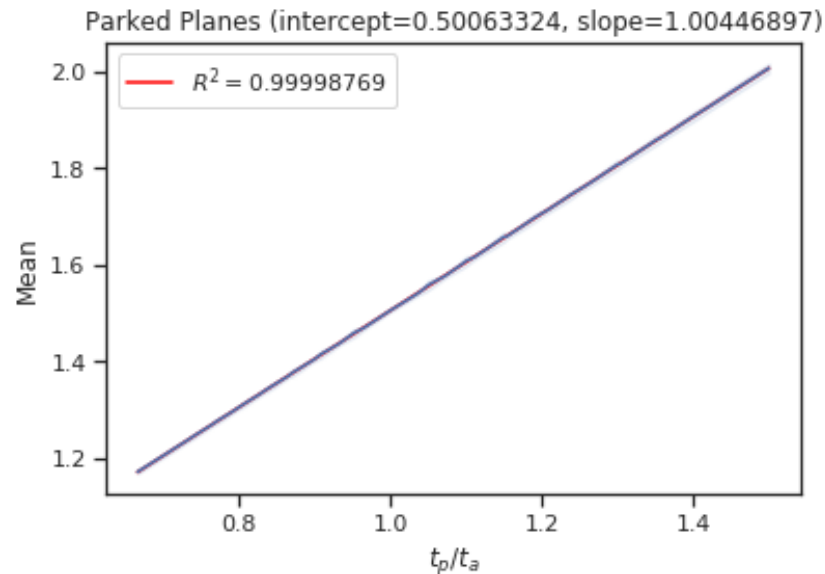
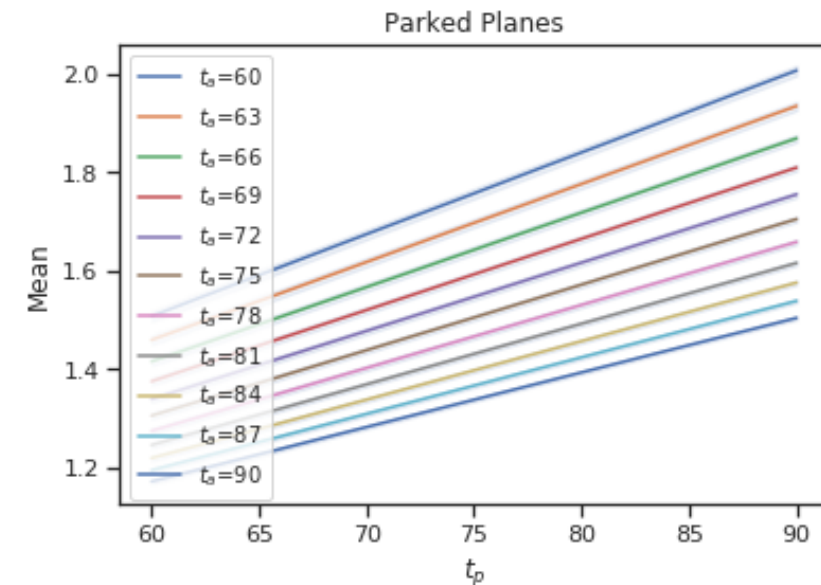


SST = $6.5 \cdot 10^7$
SSE = $9.2 \cdot 10^3$ (0.01%)

CI on the results can be computed for the *Parked Planes* only



Parked Planes Analysis:



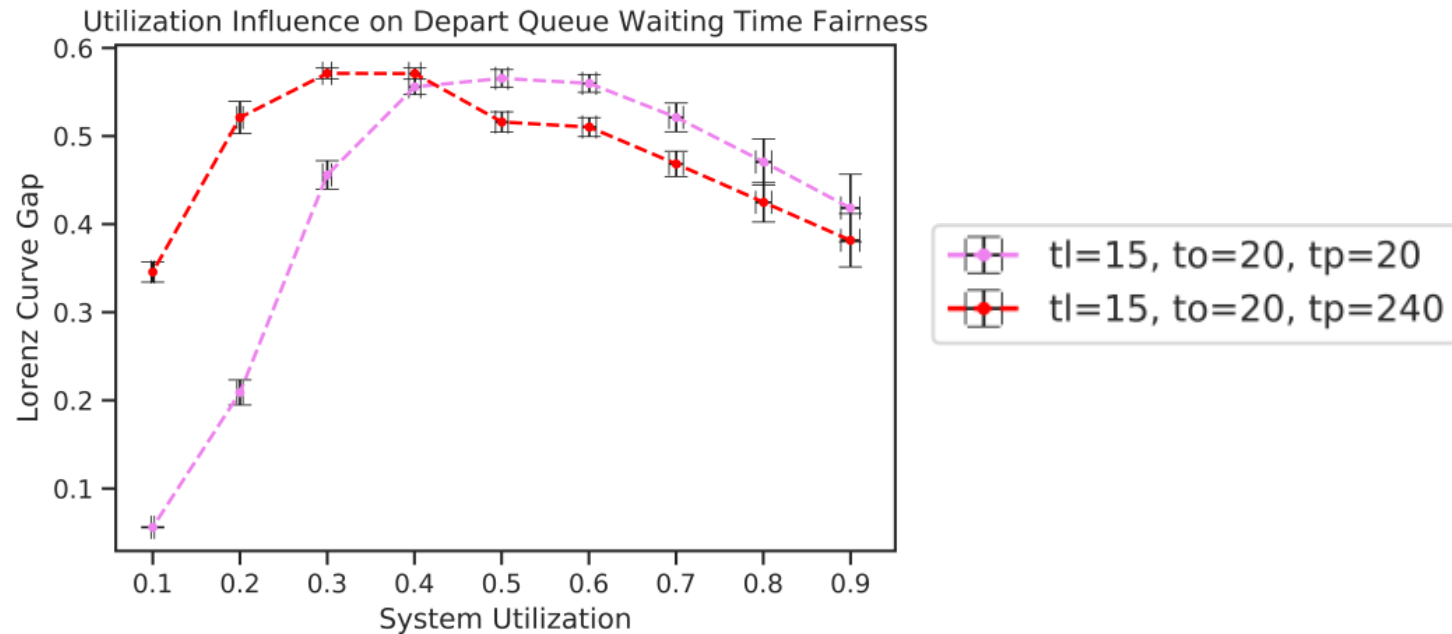
$$E[PP] = \frac{t_P}{t_A} + 0.5$$

System Fairness Analysis

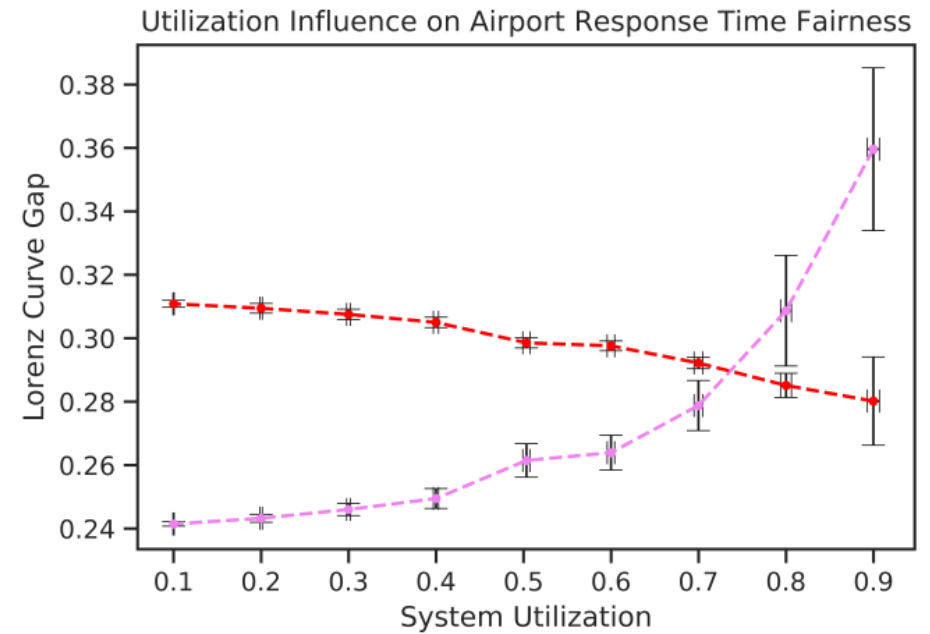
Fairness mainly influenced by three factors:

- 1) System Utilization Factor ρ .
- 2) Parking Time t_p , which decouples the two queues.
- 3) Number, weights and *likeliness* of the influencing parameters (CLT).

Queue Waiting Time Fairness



Airport Response Time Fairness



The two fairnesses are not directly related

Concluding Remarks

The analysed system is *unfair by nature*, with trends alternating in time spikes of high and dips of low values, a behaviour that can be mainly attributed to the mutually exclusive utilization of a single shared resource (the *runway*) by the two queues.

Performance-increasing Proposals

- 1) Introduce additional runways, which allows for a linear scaling of the system's equivalent service rate:

$$\mu_E = N \frac{\mu_L \mu_O}{\mu_L + \mu_O} \Rightarrow \lambda_A < N \frac{\mu_L \mu_O}{\mu_L + \mu_O} \quad N = \text{Number of Runways}$$

- 2) In a real-world scenario, all necessary measures should be taken in order to limit as much as possible the *randomness* of the system (e.g. by scheduling flights and enforcing strict time protocols within the airport).