



SIMULATION ASSIGNMENT THE UITHOFLIJN

ORESTIS MELKONIAN

CHRIS ARONIS

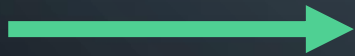
PROBLEM DESCRIPTION

- A new tram-line connecting Utrecht with the Utrecht University
- Nine stops from Central station to P+R De Uithof
- The line operates from 06:00 to 21:30
- Two different timetables one for each end station
- All trams have a fixed capacity of 420 passengers

PROBLEM DESCRIPTION

Questions to be answered:

- Feasible frequencies of the tram
- Maximum amount of passengers that line can handle
- Possible measures to improve the operational performance



SIMULATION

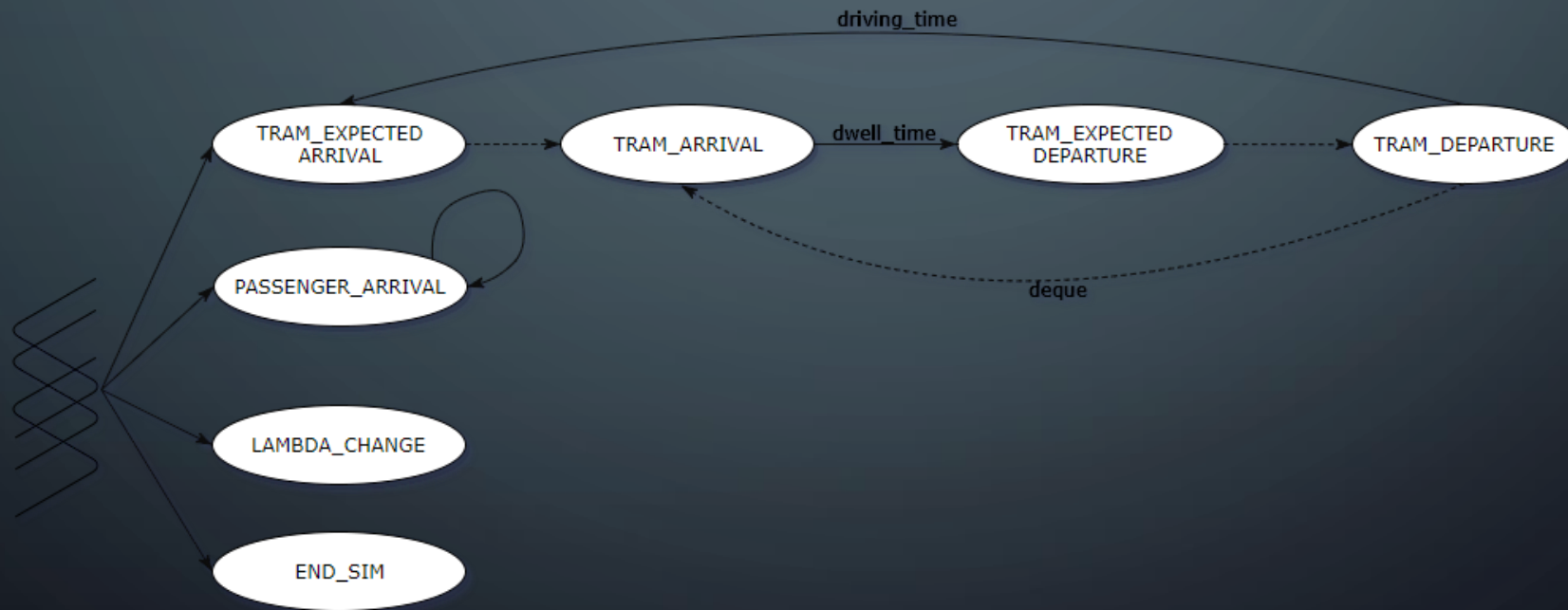
PROBLEM DESCRIPTION

Simulation model:

- Events
- Initialization
- State
- Event handlers
- Performance Measures

PROBLEM DESCRIPTION

Event graph:



PROBLEM DESCRIPTION

Performance Measures

- Punctuality:
 - $\text{departure delay} = t_{\text{actual}} - t_{\text{timetable}}$
- Passenger Waiting Times:
 - $\text{waiting time} = t_{\text{boarding}} - t_{\text{arrival}}$
- Stop Congestion:
 - $\text{congestion}_{\text{avg}}(\text{stop}) = \frac{\sum_{t \in T} \text{stop.capacity}(t)}{T}$

INPUT ANALYSIS

Data derived from the bus 12 route



Fitting

- Entering passengers
 - Poisson process, varies (λ) every 15 min.
 - Exponential distribution to model interarrival times.
- Leaving passengers
 - Transformation into percentages
 - Beta distribution (α, b)

Data derived from Nieuwegein-tramline

- Run-times
 - Gamma distribution

OUTPUT ANALYSIS

Questions answered by the experiments:

- Feasible frequencies of the tram

f	\overline{wt}	$\overline{dd_{PR}}$	$\overline{dd_{CS}}$	\overline{cong}
4	1m 18s	51s	9s	8.86
5	1m 48s	0s	0s	11.04
6	2m 04s	0s	0s	13.55
7	2m 33s	0s	0s	16.10
8	2m 56s	0s	0s	19.37
9	3m 22s	0s	0s	19.76
10	3m 55s	0s	0s	23.75
11	4m 17s	0s	0s	24.55

OUTPUT ANALYSIS

Questions answered by the experiments:

- Measures to improve operational performance

f	$\overline{dd_{PR}}$	$\overline{dd_{CS}}$
1	4h 15m 22s	4h 17m 09s
2	2h 38m 56s	2h 39m 04s
3	47m 56s	45m 20s
4	51s	7s
5	0s	0s

OUTPUT ANALYSIS

Scenarios:

- Extra tram, 14 trams instead of 13
- Better technology

Scenario	nt	db	q	f
A	14	10%	q_{base}	f_{base}
B	13	1%	$q_{base} - 2$	f_{base}

OUTPUT ANALYSIS

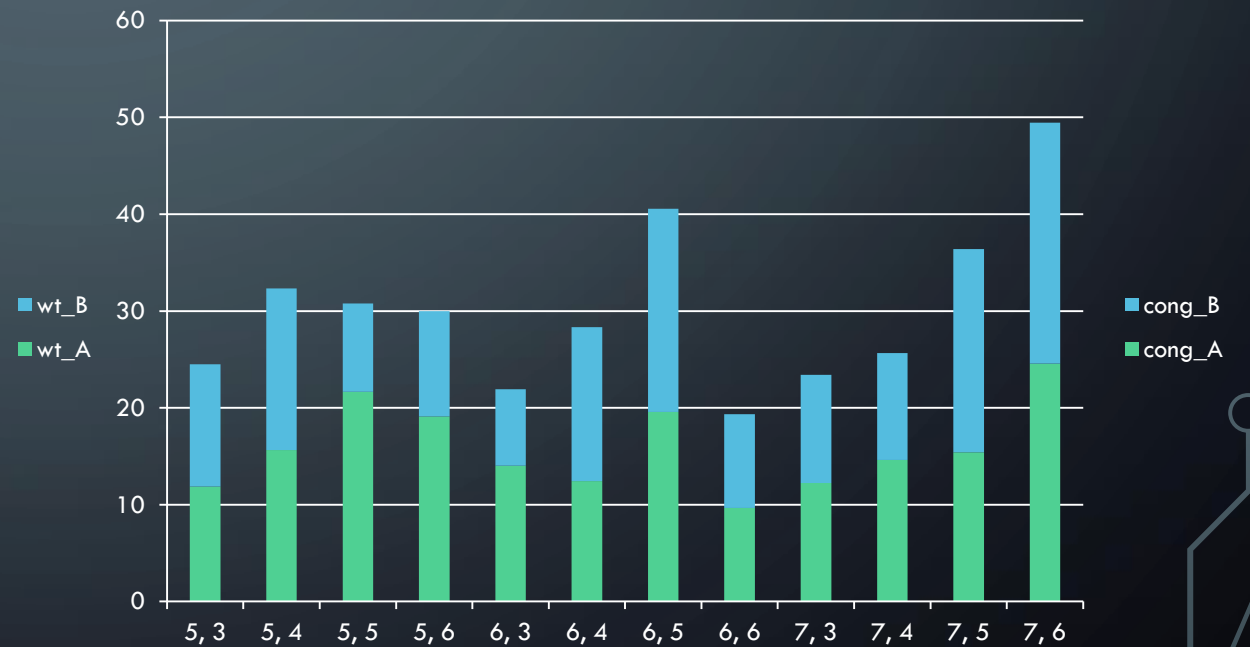
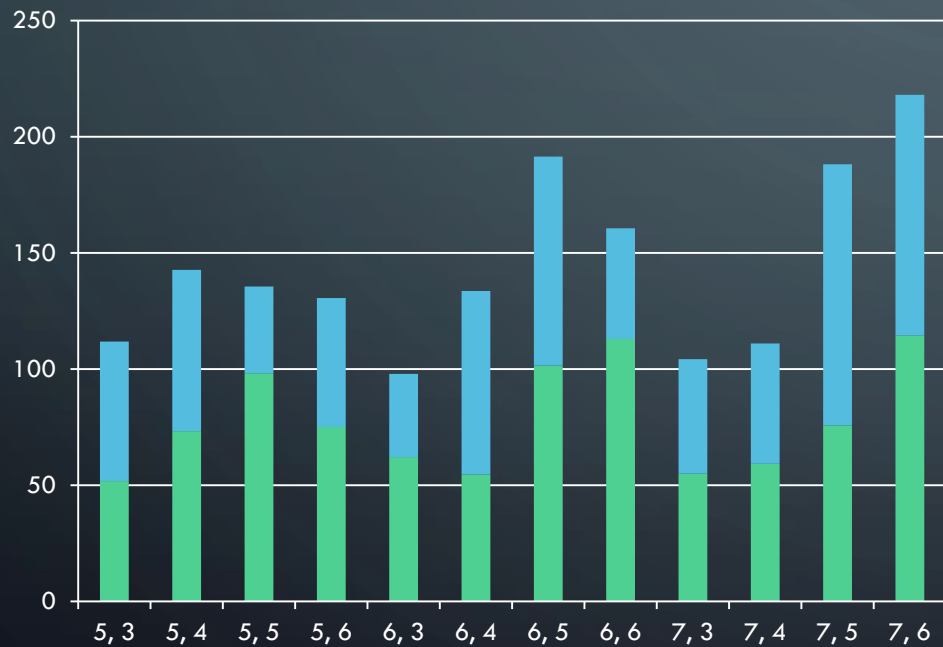
Scenarios Results:

- During peak hours

q_{base}	f_{base}	\overline{wt}_A	\overline{wt}_B	\overline{cong}_A	\overline{cong}_B
5	3	51.8	60.12	11.89	12.6
5	4	73.3	69.38	15.66	16.67
5	5	98.17	37.35	21.67	9.1
5	6	75.08	55.54	19.12	10.85
6	3	62.11	35.9	14.04	7.89
6	4	54.77	78.86	12.43	15.9
6	5	101.48	90.0	19.56	21.0
6	6	112.92	47.69	9.67	9.67
7	3	55.0	49.28	12.24	11.17
7	4	59.28	51.72	14.62	11.02
7	5	75.76	112.38	15.42	20.98
7	6	114.44	103.62	24.56	24.9

OUTPUT ANALYSIS

Scenarios Results:



OUTPUT ANALYSIS

Scenarios Comparison:

- Paired t-confidence intervals
 - $\alpha=0.05$

q_{base}	f_{base}	\overline{Z}_{wt}	$S_{z_{wt}}^2$	\overline{Z}_{cong}	$S_{z_{cong}}^2$
5	3	-12.22	50.33	-1.91	5.06
5	4	10.7	0.66	0.92	1
5	5	43.38	207.9	6.08	0.02
5	6	8.97	125.8	2.585	29.46
6	3	27.78	2.343	6.24	0
6	4	-15.05	71.18	-1.48	10.68
6	5	19.12	534.2	-0.27	6.82
6	6	70.55	11.84	15.58	0.93
7	3	5.93	267.1	2.39	6.17
7	4	5.30	148.13	4.44	6.82
7	5	-28.1	293.8	-3.36	5.96
7	6	25.51	124.6	6.11	46.03

OUTPUT ANALYSIS

Scenarios Comparison:

- Computed confidence intervals

q_{base}	f_{base}	$Z_{wt}^{95\%}$	$Z_{cong}^{95\%}$
5	3	$[-13.6, -10.8] < 0$	$[-2.3, -1.4] < 0$
5	4	$[10.5, 10.8] > 0$	$[0.7, 1.1] > 0$
5	5	$[40.5, 46.2] > 0$	$[6, 6.1] > 0$
5	6	$[6.7, 11.1] > 0$	$[1.5, 3.6] > 0$
6	3	$[27.4, 28] > 0$	$[6.2, 6.2] > 0$
6	4	$[-16.7, -13.3] < 0$	$[-2.1, -0.8] < 0$
6	5	$[14.5, 23.7] > 0$	$[-0.7, 0.2] = 0$
6	6	$[69.8, 71.2] > 0$	$[15.3, 15.7] > 0$
7	3	$[2.6, 9.1] > 0$	$[1.8, 2.8] > 0$
7	4	$[2.8, 7.7] > 0$	$[3.9, 4.9] > 0$
7	5	$[-31.5, -24.6] < 0$	$[-3.8, -2.8] < 0$
7	6	$[23.2, 27.7] > 0$	$[4.76, 7.4] > 0$

VALIDATION

Artificial dataset results:

f	\overline{wt}	$\overline{dd_{PR}}$	$\overline{dd_{CS}}$	\overline{cong}
4	1m 41.81s	0s	0s	39.13
5	1m 48.99s	0s	3.59s	46.37
6	2m 1.5 s	1.4s	0s	46.7
7	3m 22.79s	0s	0s	78.8
8	8m 29.15s	0s	0s	200.29
9	12m 16.7s	0s	0s	308.72
10	12m 56.1s	0s	0s	356.47
11	12m 47.6s	0s	0s	440.33