

Marmara University IE3081



Toll Road Simulation Project

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Step 1

We will model a toll road simulation on highways. There will be many vehicles that want to enter the tollway. Each type of vehicle will have a different speed. It is a discrete and dynamic stochastic system.

System components:

Entities:

- Vehicle.
- Booth.

Attributes:

- Vehicle Type
- Booth process time

Activities:

- Vehicle waiting in queue.
- Booth process time.

Event:

- Vehicle Entering queue.
- Vehicle Exiting queue.
- Vehicle Passing booth.

State Variables:

- Number of vehicles on the queue.

Relations Between System Components:

The vehicles will enter a queue belonging to a booth, they will select the emptiest queue. After their turn comes, they will continue to the booth and do their payment. After the booth processes they will continue their way on the toll road.

Step 2

Objectives:

An objective of this simulation is to find and fix the bottleneck which arises on the toll road booths.

Another objective is to Minimize the vehicle waiting time while minimizing the operation cost of the booths to maximize the profit.

Redefinition of the system components:

Entities:

- Vehicles
 - Car
 - Motorcycle
 - Truck
 - Bus
 - Lorry
- Toll Booths.

Attributes:

- Vehicles: Vehicle type, entry time, exit time
- Booth: Toll booth ID, status (open/closed), process time,

Activities:

- Vehicle waiting in queue.
- Toll fee calculation.
- Payment processing.

Events:

- Vehicle entering the toll road.
- Vehicle entering booth queue.
- Vehicle exiting booth queue.
- Vehicle reaching a toll booth.
- Vehicle exiting the toll booth.

State Variables:

- Number of vehicles on the toll road.
- Queue length at toll booths.

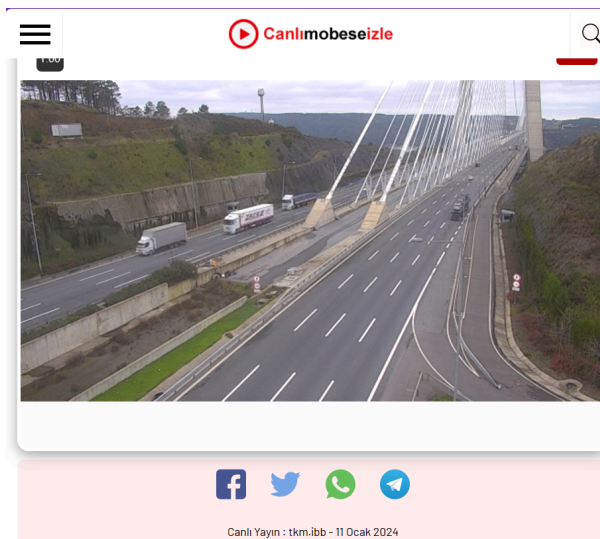
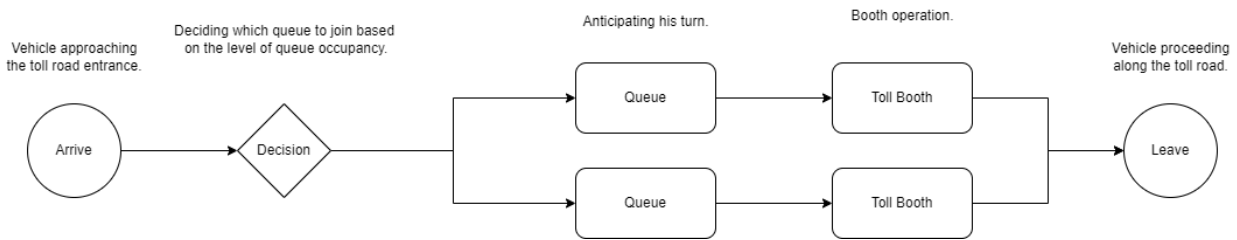
The performance metrics:

- The average waiting times in the queues.
- The average utilization of the booths.
- The Average time spent in the system per vehicle

Alternative system design:

Our alternative system design is testing with varying numbers of toll booths. We will increase the booth number and test both booth utilization and wait times. We estimate that our wait times will decrease but also utilization of booths will decrease which means a waste of resources but an increase of customer satisfaction.

Conceptual Model:



car = 39.5%
lorry = 28%
truck = 26.5%
bus 4.3%
Motorcycle 1.7%

one vehicle every 2 seconds

Step 3

Input Parameters:

Car source: exponential(0.5) / 0.395
Lorry source: exponential(0.5) / 0.280
Truck source: exponential(0.5) / 0.265
Bus source: exponential(0.5) / 0.043
Motorcycle source: exponential(0.5) / 0.017

Booth service time: normal(2, 6)

Output Parameters before change:

Average waiting time of customers in queues:

Queue 1	Queue 2
224.4374163	223.3842124
228.1165257	226.5410563
203.1518718	205.6415374

Average utilization of booths:

Booth 1	Booth 2
0.982	0.984
0.987	0.988
0.985	0.990

The Average time spent in the system per vehicle:

Average time spend in the system
258.195705
313.39699
280.80476

Output Parameters after change:

Average waiting time of customers in queues:

Queue 1	Queue 2	Queue 3	Queue 4	Queue 5	Queue 6
0.554873984	0.800839228	1.213536785	1.314287975	1.132484642	1.11493609
0.540615385	1.063204403	1.437925072	1.08159306	1.103952555	1.075973384
0.591715447	1.091207317	1.247709677	1.087942424	1.060729097	1.151566038

Average utilization of booths:

Booth 1	Booth 2	Booth 3	Booth 4	Booth 5	Booth 6
0.41	0.525	0.609	0.542	0.49	0.447
0.405	0.512	0.59	0.51	0.466	0.445
0.422	0.555	0.62	0.54	0.507	0.44

The Average time spent in the system per vehicle:

Average time spend in the system
24.92927833
24.74093714
25.24202333

Step 4

Estimate of the mean values:

Before change:

Avg waiting time for queue 1: 218.5686046
Avg waiting time for queue 2: 218.5222687
Avg utilization of booth 1: 0.984666667
Avg utilization of booth 2: 0.987333333
Average time spent in the system per vehicle: 284.132485

After change:

Avg waiting time for queue 1: 0.562401605
Avg waiting time for queue 2: 0.985083649
Avg waiting time for queue 3: 1.299723845
Avg waiting time for queue 4: 1.161274486
Avg waiting time for queue 5: 1.099055431
Avg waiting time for queue 6: 1.114158504
Avg utilization of booth 1: 0.412333333
Avg utilization of booth 2: 0.530666667
Avg utilization of booth 3: 0.606333333
Avg utilization of booth 4: 0.530666667
Avg utilization of booth 5: 0.487666667
Avg utilization of booth 6: 0.444
Average time spent in the system per vehicle: 24.97074627

95% confidence interval:

By using the formula: $\text{mean} \pm 1.96 * (\text{stdev} / \sqrt{n})$

Before change:

Avg waiting time for queue 1: $218.5686046 \pm 15.25113012$
Avg waiting time for queue 2: $218.5222687 \pm 12.74885938$
Avg utilization of booth 1: $0.984666667 \pm 0.002847814$
Avg utilization of booth 2: $0.987333333 \pm 0.003457115$
Average time spent in the system per vehicle: $284.132485 \pm 25.64032918$

After change:

Avg waiting time for queue 1: $0.562401605 \pm 0.029838876$

Avg waiting time for queue 2: $0.985083649 \pm 0.181253363$

Avg waiting time for queue 3: $1.299723845 \pm 0.136810392$

Avg waiting time for queue 4: $1.161274486 \pm 0.149996246$

Avg waiting time for queue 5: $1.099055431 \pm 0.040882188$

Avg waiting time for queue 6: $1.114158504 \pm 0.042777358$

Avg utilization of booth 1: $0.412333333 \pm 0.009886727$

Avg utilization of booth 2: $0.530666667 \pm 0.024955281$

Avg utilization of booth 3: $0.606333333 \pm 0.017174094$

Avg utilization of booth 4: $0.530666667 \pm 0.020284922$

Avg utilization of booth 5: $0.487666667 \pm 0.023310362$

Avg utilization of booth 6: 0.444 ± 0.004080065

Average time spent in the system per vehicle: $24.97074627 \pm 0.286413915$

The Estimation of the total number of replications needed to estimate mean output parameters with 10% enhancement (narrowing the CI for 10%):

By doing $0.9 \times (\text{width})$ we can narrow it down 10% but our confidence of 95% will suffer because of this.

New Interval for queue 1 = ± 13.72601711

New Interval for queue 2 = ± 11.47397345

New Interval for booth 1 = ± 0.002563033

New Interval for booth 2 = ± 0.003111404

New Interval for avg time spent in the system = ± 23.07629627

If we consider the ϵ to be:

For the queues to be: 210

For the booths to be: 0.9846

For the time spent to be: 265

This would mean that our number of estimations(3) are enough.

95% prediction interval:

By using the formula: $\text{mean} \pm 1.96 * (\text{stdev} * \sqrt{(1+1/n)})$

Before change:

Avg waiting time for queue 1: $218.5686046 \pm 30.50226024$

Avg waiting time for queue 2: $218.5222687 \pm 25.49771877$

Avg utilization of booth 1: $0.984666667 \pm 0.005695628$

Avg utilization of booth 2: $0.987333333 \pm 0.00691423$

Average time spent in the system per vehicle: $284.132485 \pm 51.28065837$

After change:

Avg waiting time for queue 1: $0.562401605 \pm 0.059677752$

Avg waiting time for queue 2: $0.985083649 \pm 0.362506727$

Avg waiting time for queue 3: $1.299723845 \pm 0.273620784$

Avg waiting time for queue 4: $1.161274486 \pm 0.299992492$

Avg waiting time for queue 5: $1.099055431 \pm 0.081764376$

Avg waiting time for queue 6: $1.114158504 \pm 0.085554717$

Avg utilization of booth 1: $0.412333333 \pm 0.019773455$

Avg utilization of booth 2: $0.530666667 \pm 0.049910562$

Avg utilization of booth 3: $0.606333333 \pm 0.034348188$

Avg utilization of booth 4: $0.530666667 \pm 0.040569843$

Avg utilization of booth 5: $0.487666667 \pm 0.046620724$

Avg utilization of booth 6: 0.444 ± 0.008160131

Average time spent in the system per vehicle: $24.97074627 \pm 0.57282783$

After the changes, are these two systems statistically different?(95% confidence interval)

$259.1617387 \pm 179.5899 > 0$

They are statistically different because the second system is a much better solution to our problem.

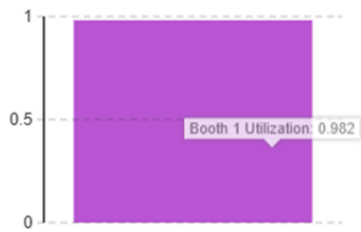
After the changes, the estimate of the additional replications needed to reduce the half-width of the confidence interval by 10% for the differences of the estimated values:

The replications needed are the same with the previous experiment.

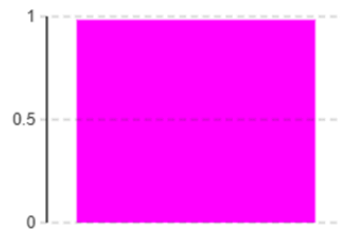
Conclusion

After seeing both systems we can confidently say that the second one is better due to the lower waiting times of the vehicles.

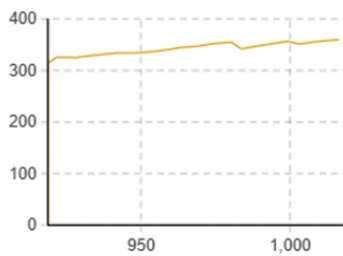
Screenshots of the model



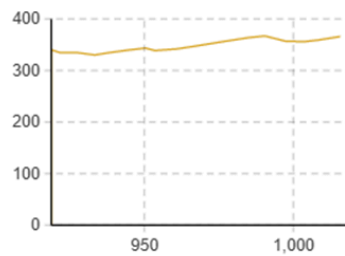
Booth 1 Utilization 0.98



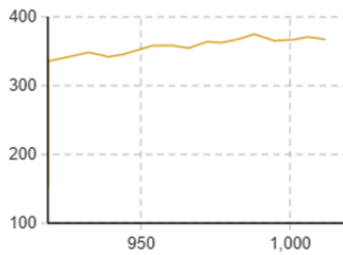
Booth 2 Utilization 0.98



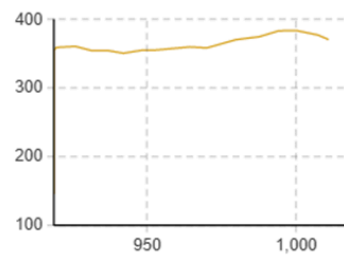
WaitingTime/Time Queue 1



WaitingTime/Time Queue 2



TotalWaitingTime/Time Queue 2

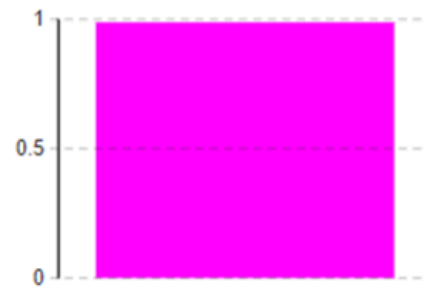


TotalWaitingTime/Time Queue 2

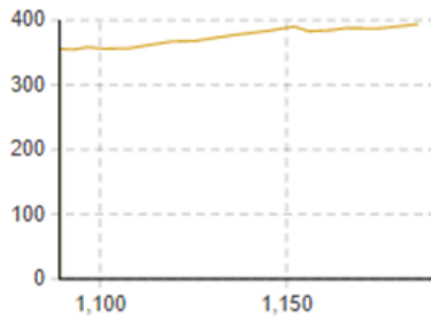
Experiment 1



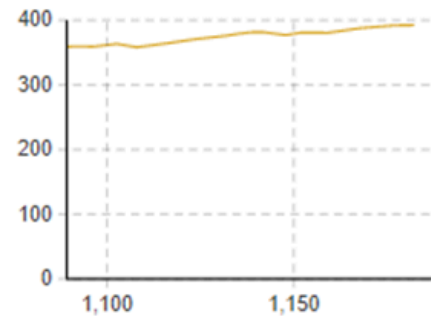
Booth 1 Utilization 0.99



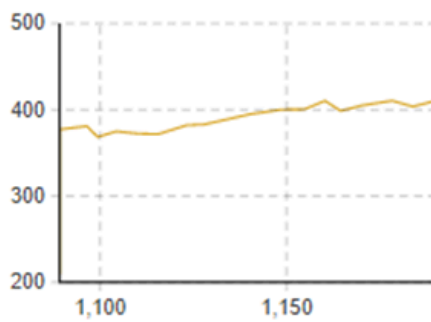
Booth 2 Utilization 0.99



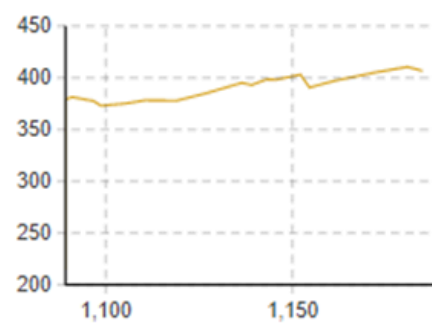
WaitingTime/Time Queue 1



WaitingTime/Time Queue 2



TotalWaitingTime/Time Queue 2



TotalWaitingTime/Time Queue 2

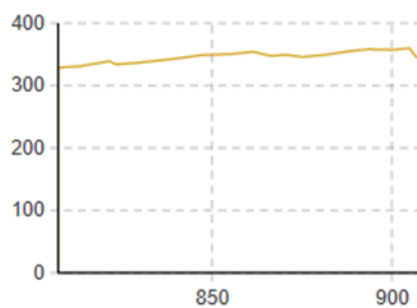
Experiment 2



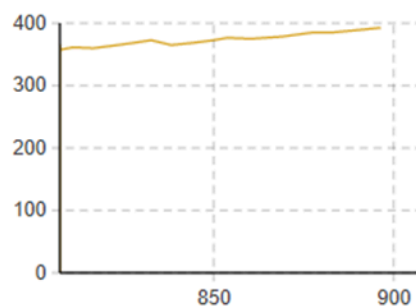
Booth 1 Utilization 0.98



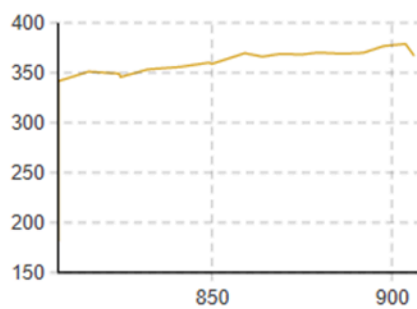
Booth 2 Utilization 0.99



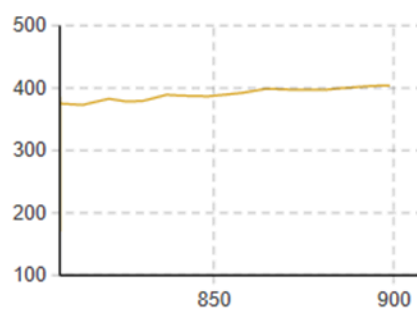
WaitingTime/Time Queue 1



WaitingTime/Time Queue 2

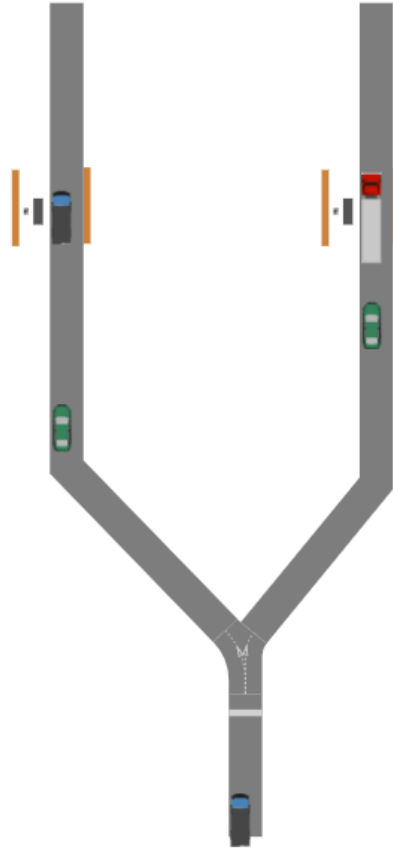


TotalWaitingTime/Time Queue 2

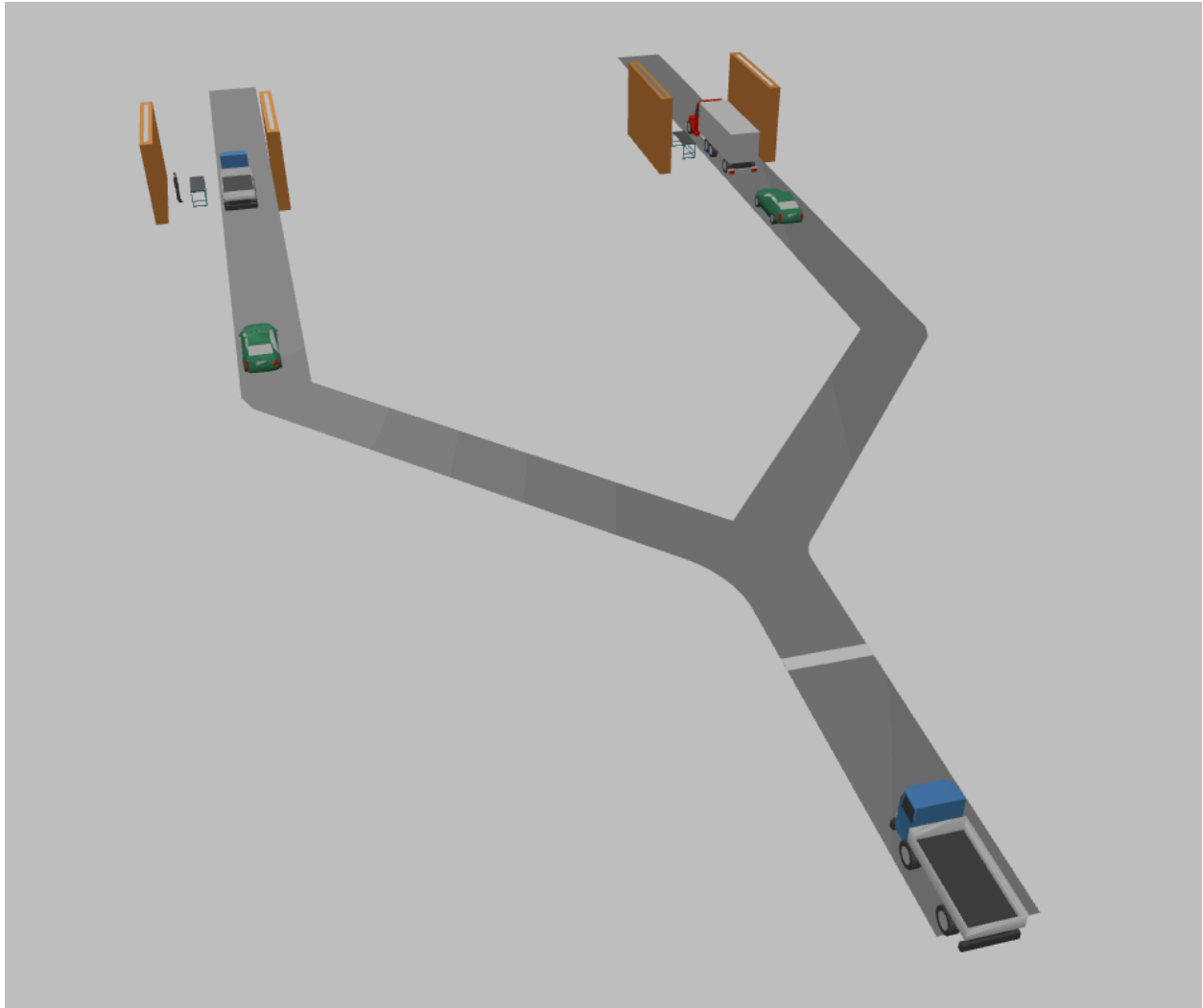


TotalWaitingTime/Time Queue 2

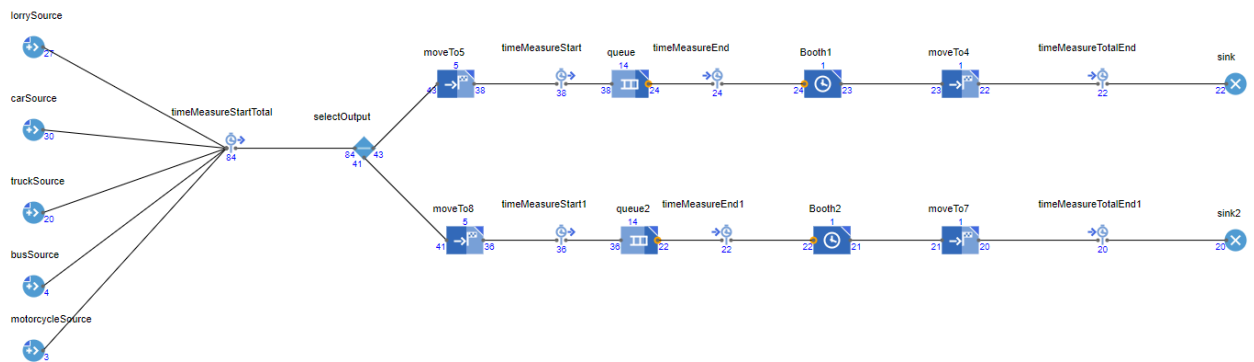
Experiment 3

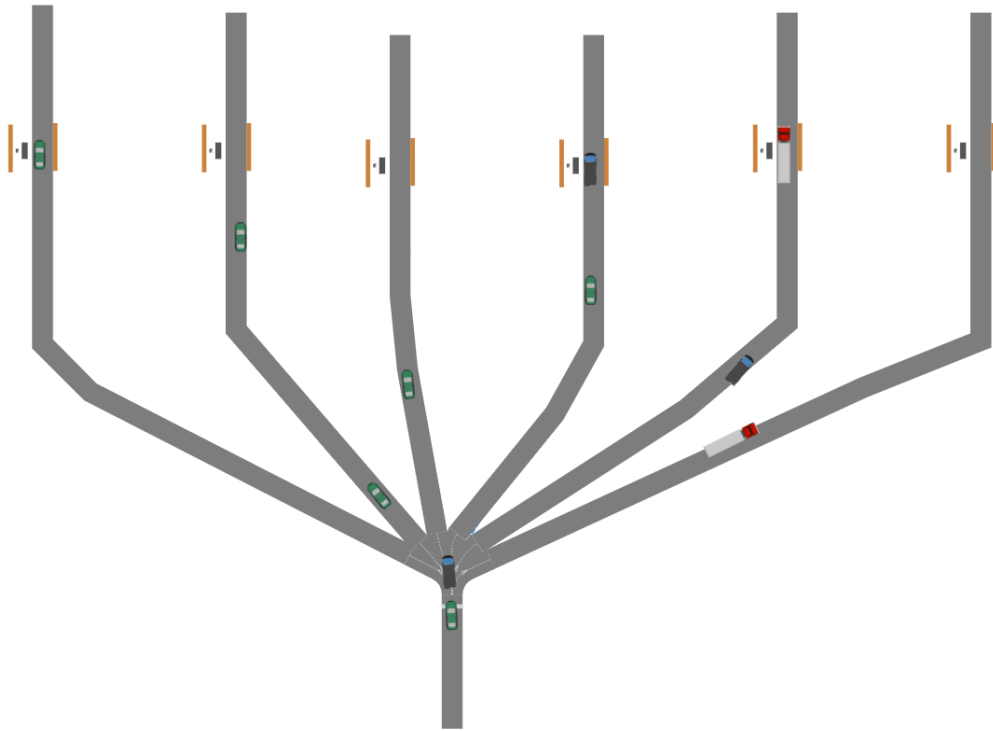


First Model with 2 booths (2D)

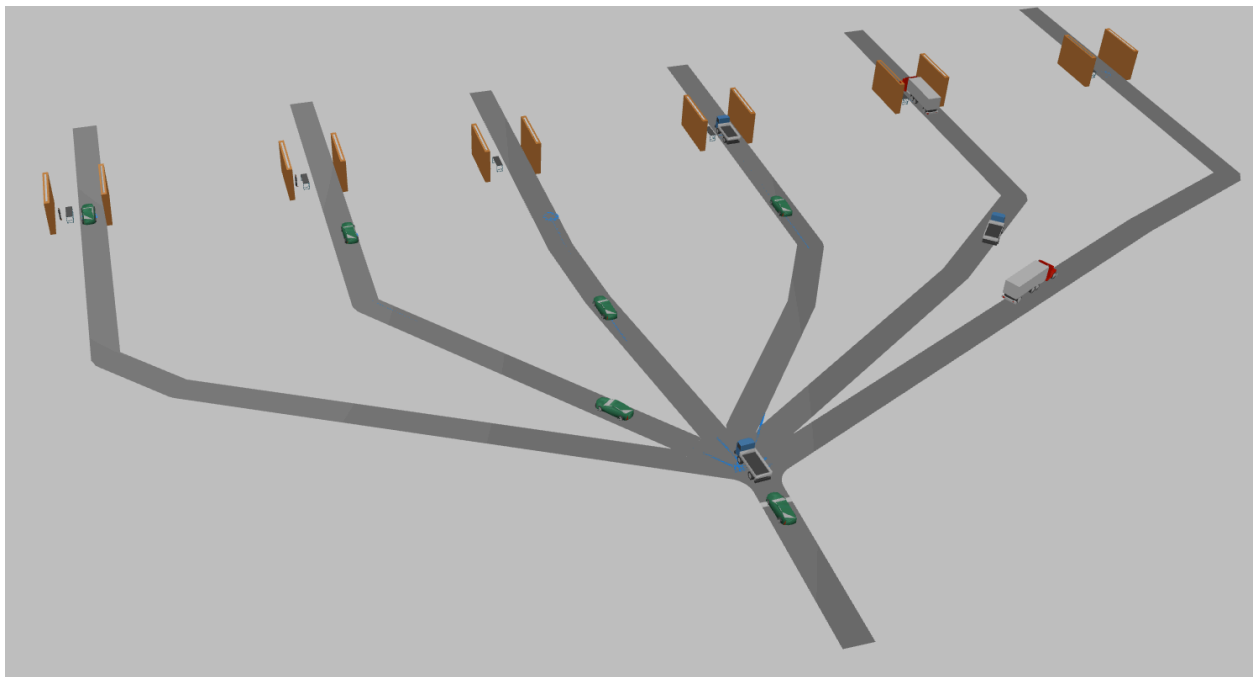


First Model with 2 booths (3D)





Second Model with 6 booths (2D)



Second Model with 6 booths (3D)

