In order to quantitatively compare the congestion situation under different conditions, we get a certain number of cars through the bottleneck in a certain amount of time. For a fixed total number of vehicles, some are platoon cars while others are background cars. They enter the highway at the same speed and may cause congestion due to lane merging at the bottleneck. The average travel time of all vehicles is considered as a quantitative measurement of congestion.

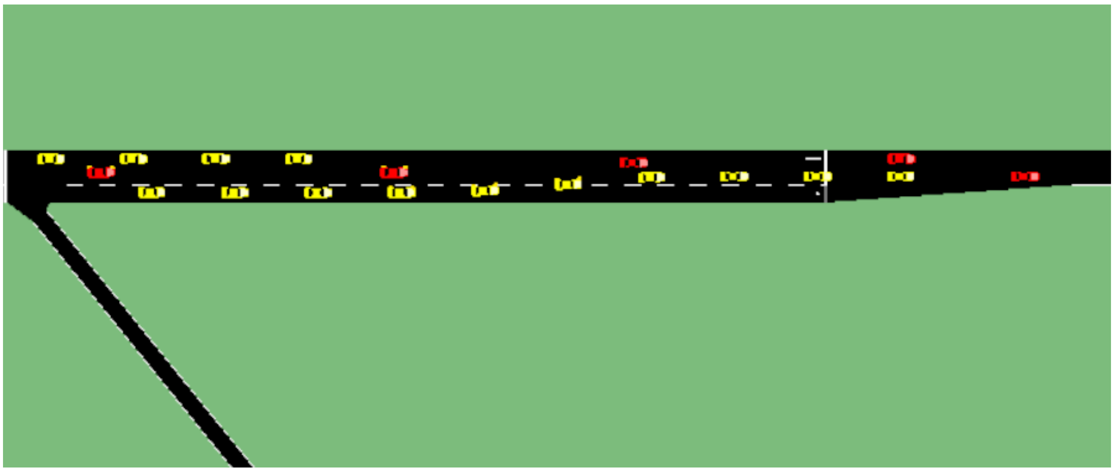
Arguments:

- Platoon ratio: the proportion of platoon vehicles in the total vehicles, which is represented in the program as the probability of occurrence at each time slot.
- Platoon length: the number of vehicles per platoon
- Platoon headway (delta): the minimal time difference between the front and rear platoons passing through the same place
- Demand: the total number of vehicles expected to pass the highway over a certain period of time

Default settings:

- Simulation time: 3000
- Depart Speed: 26.82
- Max Speed: 26.82
- Highway length: 1200
- Platoon delta (headway): 0
- Platoon length: 10
- Platoon ratio: 0.5
- Demand: 9000

Thus the minimum travel time is about 1200/26.82 = 44.74

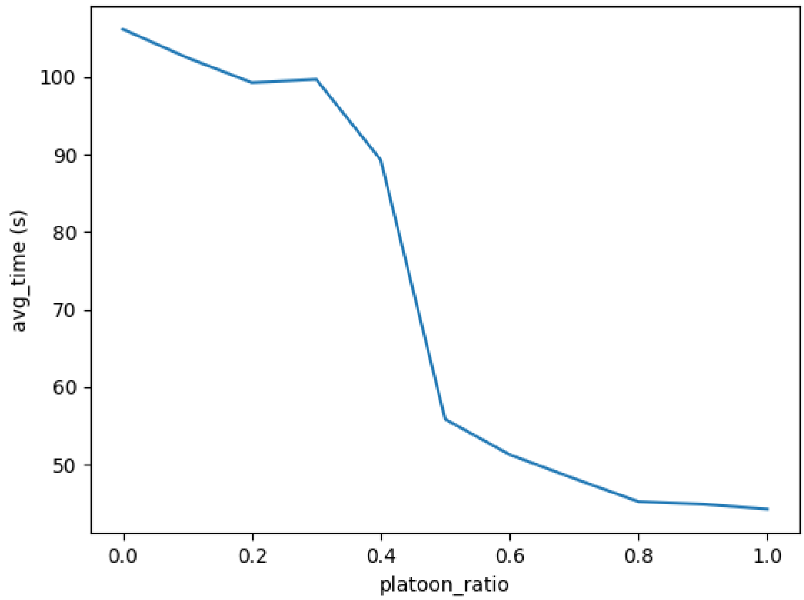


The bottleneck is showed in the figure and the platoon is changing its lane. Since three lanes turn into two lanes at the bottleneck, it will cause congestion easily.

1 Relationship between Average Travel Time and Arguments

1.1 Relationship between average travel time and platoon ratio (length=10, delta=0)

Ratio	Throughput	Avg Travel Time
0	3088	106.15
0.1	3236	102.47
0.2	3362	99.27
0.3	3505	99.69
0.4	3614	89.31
0.5	3679	55.85
0.6	3690	51.29
0.7	3698	48.21
0.8	3699	45.21
0.9	3698	44.89
1	3697	44.26

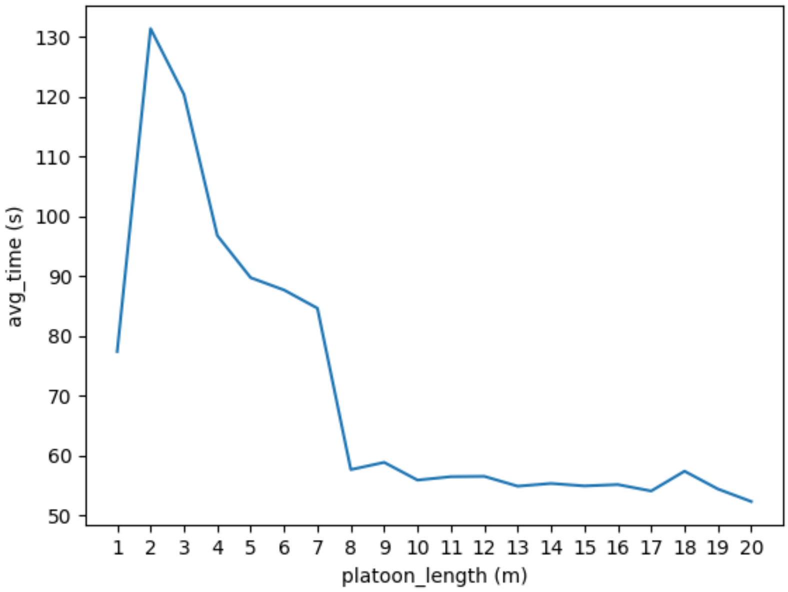


Result: As platoon ratio is larger, the average travel time decreases.

Interpretation: Since the total vehicle number is fixed, the more platoons, the less background vehicles. More platoons help save road space and it also indicates that there are more vehicles are under control.

1.2 Relationship between average travel time and platoon length (ratio=0.5, delta=0)

Length	Throughput	Avg Travel Time
1	2280	77.34
2	3130	131.33
3	3385	120.33
4	3593	96.74
5	3613	89.69
6	3640	87.63
7	3619	84.58
8	3673	57.60
9	3685	58.81
10	3679	55.85
11	3677	56.43
12	3691	56.48
13	3682	54.83
14	3689	55.29
15	3686	54.88
16	3696	55.10
17	3686	54.03
18	3694	57.34
19	3685	54.36
20	3686	52.27

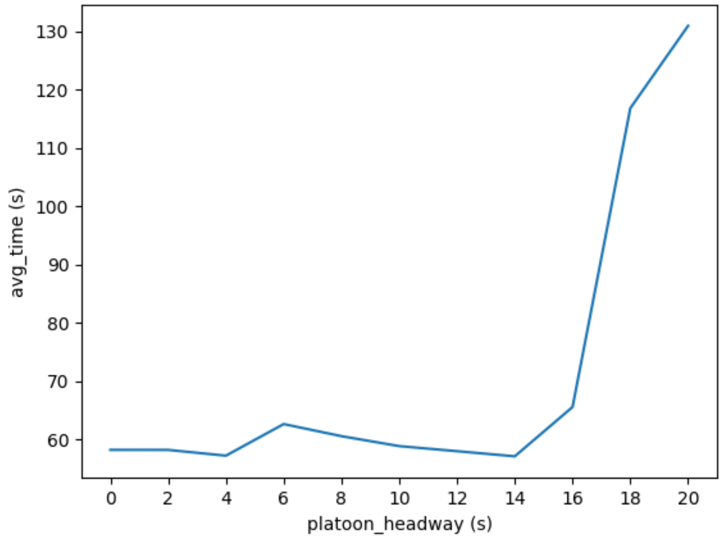


Result: As platoon length is larger, the average travel time increases and then decreases to convergence.

Interpretation: When the vehicles are all background vehicles, they are relatively flexible to change lanes and when there are a large amount of vehicles in one platoon, more distance reduced between platoon vehicles makes it less likely to cause congestion.

1.3 Relationship between average travel time and platoon headway (length=10, ratio=0.5)

Delta	Throughput	Avg Travel Time
0	3681	58.21
2	3680	58.21
4	3663	57.22
6	3666	62.64
8	3677	60.56
10	3670	58.86
12	3663	57.99
14	3672	57.11
16	3679	65.57
18	3397	116.81
20	3199	130.94



Result: As platoon headway is larger, the average travel time increases.

Interpretation: A large headway leads to a large distance between vehicles in the platoon, which takes up a lot of road resources. Thus if the headway is large, it will more easily cause congestion.

1.4 Demand

Here shows the effect of demand on the average travel time. It's in line with our expectations that with larger demand, the average travel time is larger as well.

Delta=0		Demand					
		2000	4000	6000	8000	10000	12000
Length	1	44.97	47.64	64.14	131.08	184.23	176.56
	2	44.59	44.68	48.24	116.21	122.52	135.15
	3	44.54	44.57	46.58	73.52	110.85	123.77
	4	44.57	44.62	46.31	61.05	112.48	112.84
	5	44.58	44.79	46.39	56.15	102.90	106.85
	6	44.61	44.85	46.23	53.85	105.74	107.29
	7	44.63	44.74	45.73	50.75	99.59	101.54
	10	44.62	44.82	46.05	49.13	94.10	101.37
	13	44.65	44.86	46.15	49.98	83.73	95.85
	16	44.74	44.91	46.26	48.33	76.98	95.83
	19	44.68	44.88	45.86	48.06	69.28	90.78

Length=10		Demand					
		2000	4000	6000	8000	10000	12000
Delta	0	44.64	44.80	46.31	50.51	95.64	94.83
	1	44.64	44.71	45.94	49.37	89.11	97.91
	2	44.63	44.81	45.86	50.02	92.66	95.37
	3	44.64	44.68	45.99	50.42	93.56	101.00
	4	44.60	44.72	45.86	49.30	93.26	98.41
	5	44.63	44.75	46.24	50.07	94.26	99.47
	6	44.61	44.74	45.87	49.48	96.95	103.27
	7	44.57	44.70	46.04	49.52	96.53	97.97
	8	44.65	44.73	46.22	49.85	97.96	98.53
	12	44.63	44.72	46.21	50.35	92.30	104.88
	16	44.66	44.75	45.93	49.52	112.04	117.15
	20	44.61	44.78	46.63	85.78	136.80	138.02

1.5 Waiting Car Number (maybe useful)

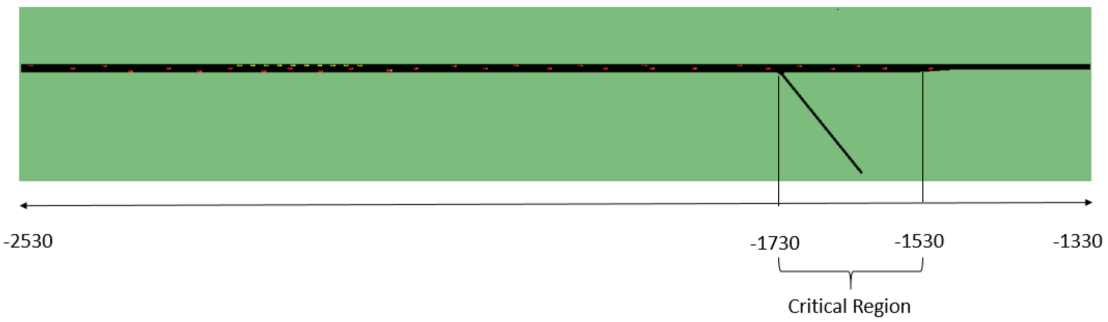
Consider the vehicles with the speed less than 10 as waiting car. Then count the number of these waiting cars in each time slot. The table indicates that with a higher ratio of platoon vehicles (less background vehicles), there are less waiting cars on the highway, which also means less congestion.

Demand=9000 Length=10 Delta=0		Waiting Car Num			
		0-10	10-50	50-100	100+
Ratio	0.1	25	133	1277	5
	0.2	25	102	1229	84
	0.3	33	199	1087	121
	0.4	142	642	640	16

	0.5	802	594	44	0
	0.6	1252	188	0	0
	0.7	1310	130	0	0
	0.8	1422	18	0	0
	0.9	1431	9	0	0

2 Deceleration

In addition to above exploration, we consider to slow down the upstream platoon when there is congestion at the bottleneck to ease the traffic.



- Critical region: the region used to determine whether there is congestion or not.
- Congestion criteria: the vehicle number exceeds a threshold (eg. 30) at the critical region.
- Deceleration strategy: when congestion criteria is satisfied, upstream platoons will slow down their speeds to a percentage of current speeds (eg. 0.5) gradually within a certain amount of time (eg. 30). This deceleration happens only once per platoon.
- Background vehicles deceleration: in order to be more realistic, if the number of background vehicles at the critical region exceeds a threshold (eg. 25), the allowed maximum speed of background vehicles are set to 0.6 times original maximum speed (26.82). Thus when platoons decelerate due to congestion, background vehicles also have to slow down.
- Settings: in all subsequent trails, length=10, delta=0, demand=9000

2.1 Comparison between no deceleration and deceleration

(length=10, delta=0)

No Deceleration			Deceleration		
Ratio	Avg Time	Throughput	Ratio	Avg Time	Throughput
0.1	104.70	3245	0.1	102.00	3247
0.2	102.89	3346	0.2	98.43	3399
0.3	95.11	3521	0.3	89.72	3547
0.4	82.97	3565	0.4	76.10	3608
0.5	65.51	3602	0.5	60.65	3621

Since there is little congestion when platoon ratio is larger than 0.5 under this situation (length=10, delta=0), only the situations no larger than 0.5 are taken into consideration. Through horizontally comparing the result in the table, we can roughly conclude that deceleration under control help relieve congestion at the bottleneck.

The time it takes for a vehicle to go through the highway at full speed is about 45. In the consideration of experimental effect and efficiency, we choose ratio to be 0.4 in the following attempts.

To provide a control group for subsequent experiments, there is a standard average travel time without deceleration manually.

	1	2	3	4	5	avg
Avg Travel Time	85.98	81.19	85.19	88.79	80.46	84.32

2.2 Single coefficient deceleration

When the number of vehicles gathered at the bottleneck is larger than the threshold (30), it will trigger deceleration mechanism.

Coefficient	Avg Travel Time
0.1	79.87
0.2	75.81
0.3	75.27
0.4	74.66
0.5	74.22
0.6	74.08
0.7	76.87
0.8	80.30
0.9	81.99

Compare to the result in 2.1 (84.32), we can conclude that deceleration mechanism is helpful to reduce congestion at the bottleneck.

2.3 Multi coefficient deceleration (heavy congestion and slight congestion)

To optimize the deceleration effect, a strategy of stepwise deceleration is proposed, including heavy and slight congestion. When the number of vehicles gathered at the bottleneck is larger than 20, we consider it as slight congestion while it is larger than 30, we consider it as heavy congestion.

Heavy Coefficient	Slight Coefficient	Avg Travel Time
0.1	0.3	74.96
	0.5	72.48
	0.7	74.80
0.3	0.5	72.90
	0.7	76.88
0.5	0.7	77.02

2.4 Gradient descent

It can help obtain a local optimum rather than a global optimum.
Start from (slight coefficient, heavy coefficient) = (0.5, 0.3)
End with (slight coefficient, heavy coefficient) = (0.5, 0.4)

		Coefficient of Heavy Congestion									
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Coefficient of Slight Congestion	0.1										
	0.2										
	0.3										
	0.4			80.97	76.53						
	0.5		78.19	77.37	75.17	77.63					
	0.6			79.78	76.14						
	0.7										
	0.8										
	0.9										
	1										

*Maybe you can start from the coefficient with best performance in 2.3
*The result seems unstable. Maybe the number of epoch should be larger.

2.5 Linear Deceleration

y: the deceleration coefficient of platoons
x: the number of vehicles at the bottleneck (from -1730 to -1530)

Let the relationship between y and x be linear and when there is no vehicles at the bottleneck, the platoons keep the original speed. Thus the linear relationship is $y=kx+1$.

k	-0.01	-0.02	-0.03	-0.04	-0.05	-0.06	-0.07	-0.08
Avg Travel Time	85.55	86.32	78.72	75.06	73.46	80.50	83.53	84.21

Result: with k from -0.01 to -0.08, the average travel time decreases first and then increased.

Interpretation: when k is quite large, it has little deceleration effect on platoons so that the result is not satisfactory. When k is too small, it will lead to unnecessary deceleration so that it may also waste much waiting time.

Tips:

1. Start from ./sum_control_2021_origincode/runner.py
2. Deceleration version: ./deceleration_version/main.py
3. Document: https://sumo.dlr.de/docs/TraCI/Vehicle_Value_Retrieval.html
4. Gui: in the function sumoBinary = checkBinary(‘’), ‘sumo-gui’ will show the graphical interfaces in SUMO while ‘sumo’ can enable you to run the program automatically, useful especially in iteration.
5. It is recommended to test for several times for each experiment since the contingency is relatively large.