**Baseline**

no VSL control

[30. 30. 30.]

mainlane 0 : traveltime= 22.81 waitingTime= 9.00" speed= 17.58

mainlane 1 : traveltime= 27.20 waitingTime= 504.00 speed= 14.79

mainlane 2 : traveltime= 13.84 waitingTime= 55.00" speed= 28.89

Rewards: 42.0000 Bottleneck speed: 3207.1372 out-in flow: 37.0000 Average Travel Time: 35.9300

**1. simulation time=3600 , control horizon= 10s, reward= out flow**

**with exploration:**

**the optimal of 300 episodes**

[33.528 33.528 17.8816]

Auxiliarylane: traveltime= 19.20 waitingTime= 0.00" speed= 20.89

Main lane 1 : traveltime= 19.08 waitingTime= 0.00" speed= 21.02

Main lane 2 : traveltime= 12.34 waitingTime= 0.00" speed= 32.37

Episode: 259 Rewards: 298.0000 Bottleneck speed: 3854.7747 out-in flow: 293.0000 Average travel time: 30.7600

------------------------save model-------------------------------, episode= 259

totally cost 9.707768678665161

**2. simulation time=3600 , control horizon= 20s, reward= bspeed**

Auxiliarylane: traveltime= 20.50 waitingTime= 0.00" speed= 19.56

mainlane 1 : traveltime= 21.37 waitingTime= 1.00" speed= 18.79

mainlane 2 : traveltime= 12.64 waitingTime= 1.00" speed= 31.60

Episode: 19 Rewards: 1833.7092 Bottleneck speed: 1833.7092 out-in flow: 249.0000 Average travel time: 32.3500

------------------------save model-------------------------------, episode= 19

**3. simulation time=3600, control horizon= 10s,**

**reward= 0.5speed+ 0.5outflow**

**the optimal of 300 episodes**

[33.528 33.528 20.1168]

Auxiliarylane: traveltime= 18.84 waitingTime= 0.00" speed= 21.28

mainlane 1 : traveltime= 18.70 waitingTime= 0.00" speed= 21.45

mainlane 2 : traveltime= 12.50 waitingTime= 0.00" speed= 31.95

Episode: 253 Rewards: 65.7836 Bottleneck speed: 3852.1430 out-in flow: 248.0000 Average travel time: 30.5500

------------------------save model-------------------------------, episode= 253

**with exploration:**

图表, 折线图

描述已自动生成

**No exploration:**

图表

描述已自动生成

**4. simulation time=3600, control horizon=10s,**

**reward=0.9bspeed + 0.1oflow**

**with exploration:**

**the optimal of 200 episodes**

[17.8816 33.528 17.8816]

Auxiliarylane: traveltime= 18.55 waitingTime= 1.00" speed= 21.61

mainlane 1 : traveltime= 18.92 waitingTime= 0.00" speed= 21.20

mainlane 2 : traveltime= 12.51 waitingTime= 0.00" speed= 31.92

Episode: 297 Rewards: 120.1658 Bottleneck speed: 3999.5281 out-in flow: 139.0000 Average travel time: 30.5300

------------------------save model------------------------------- ,episode= 297

totally cost 6.981377601623535

**Comparison with no VSL control**

**表格

描述已自动生成**

图表, 折线图

描述已自动生成

The learning process with exploration: hard to converge

图表

描述已自动生成

The learning process without exploration: local optimal

Speed profile with vsl control -

图表

中度可信度描述已自动生成

auxiliary lane

图表

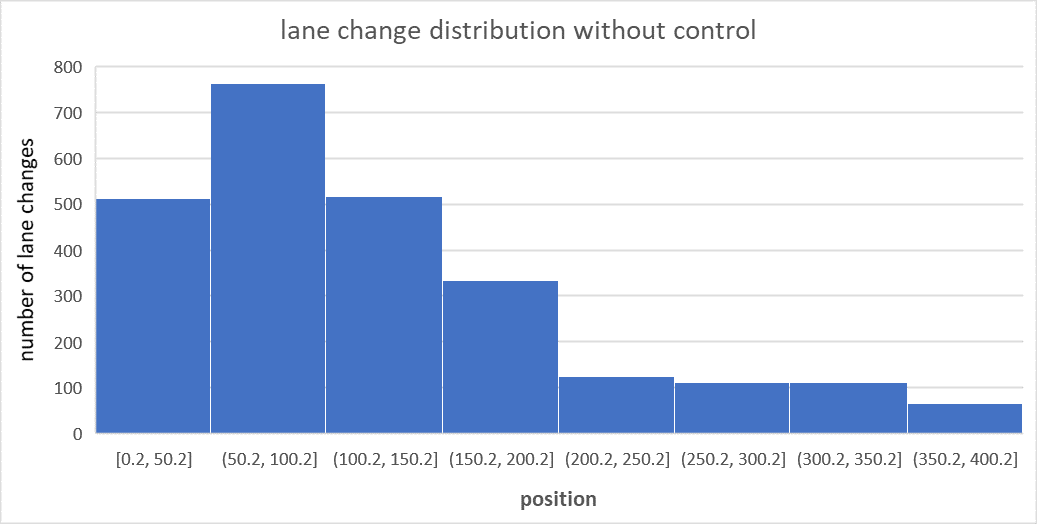
描述已自动生成

Mainlane1

Conclusion: variable speed limit can only increase vehicular velocity and improve the overall traffic efficiency (like average travel time, total waiting time, but cannot resolve the bottleneck problem at merging area. This is because that the bottleneck problem is caused by frequently lane changing behavior at merging area, so we need lane change distribution control to erase the congestion.

**Lane change distribution**

Baseline with no speed control



文本

描述已自动生成

**Baseline**

no VSL control

[30. 30. 30.]

mainlane 0 : traveltime= 22.81 waitingTime= 9.00" speed= 17.58

mainlane 1 : traveltime= 27.20 waitingTime= 504.00 speed= 14.79

mainlane 2 : traveltime= 13.84 waitingTime= 55.00" speed= 28.89

Rewards: 42.0000 Bottleneck speed: 3207.1372 out-in flow: 37.0000 Average Travel Time: 35.9300

with lane change control (random numer)

mainlane 0 : traveltime= 16.83 waitingTime= 24.00" speed= 23.79

mainlane 1 : traveltime= 16.51 waitingTime= 8.00" speed= 24.24

mainlane 2 : traveltime= 11.69 waitingTime= 0.00" speed= 34.15

Average Travel Time: 28.9200

with lane change control (random numer3)

mainlane 0 : traveltime= 15.44 waitingTime= 25.00" speed= 25.92

mainlane 1 : traveltime= 14.91 waitingTime= 3.00" speed= 26.83

mainlane 2 : traveltime= 11.51 waitingTime= 0.00" speed= 34.66

Rewards: 4967.6010 Bottleneck speed: 4967.6010 out-in flow: 721.0000 Average Travel Time: 27.8000

totally cost 20.087838411331177

图形用户界面

描述已自动生成

图形用户界面

描述已自动生成

The speed profiles of each simulation are not completely consistent, because the lane change control is realized by assign a random number to each vehicle, resulting in random lane changing position.

Lane change control + DVSL

**Reward = bspeed, control horizon=10s**

图表

描述已自动生成

**the optimal**

mainlane 0 : traveltime= 14.86 waitingTime= 3.00" speed= 26.91

mainlane 1 : traveltime= 14.49 waitingTime= 0.00" speed= 27.58

mainlane 2 : traveltime= 11.37 waitingTime= 0.00" speed= 35.09

Episode: 123 Rewards: 5142.1072 Bottleneck speed: 5142.1072 out-in flow: 834.0000 Average travel time: 27.4200

------------------------save model------------------------------- ,episode= 123

totally cost 19.948671340942383

**the last episode to plot speed profile**

[33.528 33.528 33.528]

mainlane 0 : traveltime= 16.78 waitingTime= 17.00" speed= 23.87

mainlane 1 : traveltime= 16.16 waitingTime= 5.00" speed= 24.78

mainlane 2 : traveltime= 11.73 waitingTime= 0.00" speed= 34.03

Episode: 299 Rewards: 4595.1359 Bottleneck speed: 4595.1359 out-in flow: 547.0000 Average travel time: 28.7800

totally cost 20.935155630111694

图表, 直方图

描述已自动生成

VSL control has no significant effect on the speed profile.

还需修改模型。

**Reward = bspeed, control horizon=1s**

图表, 折线图

描述已自动生成

不收敛！！！！！！！！！！！！！！！！！！！！！！！

**the optimal**

[17.8816 33.528 17.8816]

mainlane 0 : traveltime= 14.26 waitingTime= 24.00" speed= 28.05

mainlane 1 : traveltime= 14.13 waitingTime= 6.00" speed= 28.26

mainlane 2 : traveltime= 11.76 waitingTime= 0.00" speed= 33.95

Episode: 31 Rewards: 51802.2183 Bottleneck speed: 51802.2183 out-in flow: 511.0000 Average travel time: 27.2000

------------------------save model------------------------------- ,episode= 31

**Adjust the reward to the bottleneck speed at 50,60,70m in the auxiliary lane.**



**Reward = bspeed, control horizon=1s**

**The optimal**

mainlane 0 : traveltime= 15.19 waitingTime= 10.00" speed= 26.35

mainlane 1 : traveltime= 14.77 waitingTime= 3.00" speed= 27.07

mainlane 2 : traveltime= 11.42 waitingTime= 0.00" speed= 34.95

Episode: 60 Rewards: 47754.2721 Bottleneck speed: 47754.2721 out-in flow: 792.0000 Average travel time: 27.6100

----------------------------save model-----------------------------, episode= 60

totally cost 23.812321662902832

图表, 折线图

描述已自动生成

**Reward =out flow, control horizon=1s**

**Reward =out flow, control horizon = 360**

图表, 折线图

描述已自动生成

**Reward =out flow, control horizon = 60**

图表, 条形图

描述已自动生成

**Reward = bspeed, control horizon = 10,** 图片包含 图形用户界面

描述已自动生成

**The optimal**

mainlane 0 : traveltime= 14.37 waitingTime= 0.00" speed= 27.85

mainlane 1 : traveltime= 13.91 waitingTime= 0.00" speed= 28.74

mainlane 2 : traveltime= 11.37 waitingTime= 0.00" speed= 35.08

Episode: 134 Rewards: 5158.6509 Bottleneck speed: 5158.6509 out-in flow: 783.0000 Average travel time: 27.0100

----------------------------save model-----------------------------, episode= 134

图表, 折线图

描述已自动生成

**Reward = bspeed, control horizon=10s**

图表, 折线图

描述已自动生成

OMNET --- SUMO

No lane change control (packet loss=1)

<lane id="gneE1\_0" traveltime="22.47" waitingTime="335.00" speed="17.85" "/>

<lane id="gneE1\_1" traveltime="23.96" waitingTime="939.00" speed="16.78"/>

<lane id="gneE1\_2" traveltime="13.94" waitingTime="230.00" speed="28.69" />

Simulation step=0.5, time=7200

**Lane change --- fix random number**

mainlane 0 : traveltime= 16.72 waitingTime= 161.00 speed= 23.89

mainlane 1 : traveltime= 17.60 waitingTime= 6.00" speed= 22.56

mainlane 2 : traveltime= 11.55 waitingTime= 0.00" speed= 34.57

Rewards: 7736.0369 Bottleneck speed: 7736.0369 out-in flow: 2095.0000 Average Travel Time: 29.1600

totally cost 116.8728895187378

**Omnet (LC) + DDPG**

**Omnet (LC) + DDPG(LC)**

mainlane 0 : traveltime= 34.12 waitingTime= 7351.3 speed= 11.76

mainlane 1 : traveltime= 37.27 waitingTime= 10616. speed= 10.80

mainlane 2 : traveltime= 17.29 waitingTime= 2254.0 speed= 23.13

Episode: 0 Rewards: 3793.6625 Bottleneck speed: 3793.6625 out-in flow: -516.0000 Average travel time: 44.3800

----------------------------save model-----------------------------, episode= 0

totally cost 151.062566280365

**Omnet (LC) + DDPG**

mainlane 0 : traveltime= 40.80 waitingTime= 5645.4 speed= 9.84"

mainlane 1 : traveltime= 43.01 waitingTime= 10560. speed= 9.37"

mainlane 2 : traveltime= 20.83 waitingTime= 6048.0 speed= 19.27

Episode: 0 Rewards: 2951.7891 Bottleneck speed: 2951.7891 out-in flow: -822.0000 Average travel time: 52.6500

----------------------------save model-----------------------------, episode= 0

totally cost 70.72624135017395

**Omnet (LC)**

manager: TraCIScenarioManager-> TraCIScenarioManagerLaunchd

<lane id="gneE1\_0" traveltime="32.60” waitingTime="2677.00" speed="12.30"

<lane id="gneE1\_1" traveltime="48.02" waitingTime="13296.00" speed="8.41"

<lane id="gneE1\_2" traveltime="20.54" waitingTime="6435.00" speed="19.52"

Average travel time: 49.81

**Omnet(无变道算法) baseline**

<lane id="gneE1\_0 traveltime="22.47" waitingTime="335.00" speed="17.85"

<lane id="gneE1\_1" traveltime="23.96" waitingTime="939.00" speed="16.78"

<lane id="gneE1\_2" traveltime="13.94" waitingTime="230.00" speed="28.69"

**Omnet(LC)-100%**

mainlane 0 : traveltime= 17.70 waitingTime= 62.00" speed= 22.61

mainlane 1 : traveltime= 18.78 waitingTime= 78.00" speed= 21.33

mainlane 2 : traveltime= 11.86 waitingTime= 0.00" speed= 33.66

Rewards: 5018.7679 Bottleneck speed: 5018.7679 out-in flow: 742.0000 Average Travel Time: 30.0700

totally cost 59.58889126777649

图表, 条形图

描述已自动生成

**Omnet(LC)+DDPG2**

mainlane 0 : traveltime= 14.53 waitingTime= 32.00" speed= 27.53

mainlane 1 : traveltime= 14.58 waitingTime= 13.00" speed= 27.41

mainlane 2 : traveltime= 11.40 waitingTime= 0.00" speed= 34.99

Episode: 7 Rewards: 5600.6663 Bottleneck speed: 5600.6663 out-in flow: 814.0000 Average travel time: 27.4200

----------------------------save model-----------------------------, episode= 7

**Omnet(LC)+DDPG1**

mainlane 0 : traveltime= 16.42 waitingTime= 44.00" speed= 24.37

mainlane 1 : traveltime= 16.97 waitingTime= 50.00" speed= 23.59

mainlane 2 : traveltime= 11.70 waitingTime= 0.00" speed= 34.12

Episode: 6 Rewards: 5210.1675 Bottleneck speed: 5210.1675 out-in flow: 719.0000 Average travel time: 29.0500

----------------------------save model-----------------------------, episode= 6

totally cost 134.338520526886

**Omnet(LC)-80%**

mainlane 0 : traveltime= 19.66 waitingTime= 119.00 speed= 20.36

mainlane 1 : traveltime= 20.70 waitingTime= 92.00" speed= 19.38

mainlane 2 : traveltime= 12.01 waitingTime= 0.00" speed= 33.24

Rewards: 4572.4335 Bottleneck speed: 4572.4335 out-in flow: 686.0000 Average Travel Time: 31.5300

**Omnet(LC)-80% + DDPG**

mainlane 0 : traveltime= 17.12 waitingTime= 66.00" speed= 23.37

mainlane 1 : traveltime= 17.68 waitingTime= 33.00" speed= 22.64

mainlane 2 : traveltime= 11.60 waitingTime= 0.00" speed= 34.40

Episode: 13 Rewards: 5112.6489 Bottleneck speed: 5112.6489 out-in flow: 809.0000 Average travel time: 29.4500

----------------------------save model-----------------------------, episode= 13

**Omnet(LC)-60%**

mainlane 0 : traveltime= 46.83 waitingTime= 15300. speed= 8.56"

mainlane 1 : traveltime= 72.54 waitingTime= 30951. speed= 5.56"

mainlane 2 : traveltime= 29.07 waitingTime= 10380. speed= 13.83

Rewards: 2983.7501 Bottleneck speed: 2983.7501 out-in flow: -1040.0000 Average Travel Time: 71.7500

**Omnet(LC)-60**% **+ DDPG**

mainlane 0 : traveltime= 18.57 waitingTime= 111.00 speed= 21.55

mainlane 1 : traveltime= 19.56 waitingTime= 57.00" speed= 20.48

mainlane 2 : traveltime= 11.66 waitingTime= 0.00" speed= 34.24

Episode: 7 Rewards: 4922.9986 Bottleneck speed: 4922.9986 out-in flow: 827.0000 Average travel time: 30.5600

----------------------------save model-----------------------------, episode= 7

不同渗透率下，只有Lane-changing distribution，在omnet中实现

**Omnet(LC)-0 %**

mainlane 0 : traveltime= 22.47 waitingTime= 335.00 speed= 17.85

mainlane 1 : traveltime= 23.96 waitingTime= 939.00 speed= 16.78

mainlane 2 : traveltime= 13.94 waitingTime= 230.00 speed= 28.69

Rewards: 3305.1356 Bottleneck speed: 3305.1356 out-in flow: -61.0000 Average Travel Time: 34.1100

**Omnet(LC)- 20 %**

mainlane 0 : traveltime= 55.47 waitingTime= 18933. speed= 7.23"

mainlane 1 : traveltime= 87.85 waitingTime= 33536. speed= 4.59"

mainlane 2 : traveltime= 41.05 waitingTime= 16873. speed= 9.81"

Rewards: 2791.7143 Bottleneck speed: 2791.7143 out-in flow: -1584.0000 Average Travel Time: 87.0000

totally cost 69.78044486045837

**Omnet(LC)- 40 %**

mainlane 0 : traveltime= 38.03 waitingTime= 9929.0 speed= 10.55

mainlane 1 : traveltime= 53.37 waitingTime= 21292. speed= 7.56"

mainlane 2 : traveltime= 28.36 waitingTime= 11416. speed= 14.16

Rewards: 3548.1181 Bottleneck speed: 3548.1181 out-in flow: -1082.0000 Average Travel Time: 60.0600

**Omnet(LC)- 60 %**

mainlane 0 : traveltime= 46.83 waitingTime= 15300. speed= 8.56"

mainlane 1 : traveltime= 72.54 waitingTime= 30951. speed= 5.56"

mainlane 2 : traveltime= 29.07 waitingTime= 10380. speed= 13.83

Rewards: 2983.7501 Bottleneck speed: 2983.7501 out-in flow: -1040.0000 Average Travel Time: 71.7500

**Omnet(LC)- 80 %**

mainlane 0 : traveltime= 19.66 waitingTime= 119.00 speed= 20.36

mainlane 1 : traveltime= 20.70 waitingTime= 92.00" speed= 19.38

mainlane 2 : traveltime= 12.01 waitingTime= 0.00" speed= 33.24

Rewards: 4572.4335 Bottleneck speed: 4572.4335 out-in flow: 686.0000 Average Travel Time: 31.5300

totally cost 134.85642504692078

**Omnet(LC)- 100 %**

mainlane 0 : traveltime= 17.70 waitingTime= 62.00" speed= 22.61

mainlane 1 : traveltime= 18.78 waitingTime= 78.00" speed= 21.33

mainlane 2 : traveltime= 11.86 waitingTime= 0.00" speed= 33.66

Rewards: 5018.7679 Bottleneck speed: 5018.7679 out-in flow: 742.0000 Average Travel Time: 30.0700

totally cost 508.04022240638733

在omnet里控制LC算法+训练好的VSL算法

**omnet(LC+fixed-VSL)-100%**

mainlane 0 : traveltime= 16.37 waitingTime= 38.00" speed= 24.44

mainlane 1 : traveltime= 16.75 waitingTime= 18.00" speed= 23.89

mainlane 2 : traveltime= 11.54 waitingTime= 0.00" speed= 34.57

Episode: 0 Rewards: 1744.0934 Bottleneck speed: 1744.0934 out-in flow: 827.0000 Average travel time: 28.8400

----------------------------save model-----------------------------, episode= 0

**omnet(LC+fixed-VSL)-80%**

mainlane 0 : traveltime= 17.32 waitingTime= 43.00" speed= 23.10

mainlane 1 : traveltime= 18.16 waitingTime= 33.00" speed= 22.04

mainlane 2 : traveltime= 11.52 waitingTime= 0.00" speed= 34.64

Episode: 2 Rewards: 1698.7384 Bottleneck speed: 1698.7384 out-in flow: 846.0000 Average travel time: 29.6600

----------------------------save model-----------------------------, episode= 2

**omnet(LC+fixed-VSL)-60%**

mainlane 0 : traveltime= 20.12 waitingTime= 678.00 speed= 19.90

mainlane 1 : traveltime= 22.99 waitingTime= 2320.0 speed= 17.45

mainlane 2 : traveltime= 15.29 waitingTime= 1983.0 speed= 26.19

Episode: 10 Rewards: 1556.9407 Bottleneck speed: 1556.9407 out-in flow: 519.0000 Average travel time: 34.0600

----------------------------save model-----------------------------, episode= 10

**omnet(LC+fixed-VSL)-20%**

mainlane 0 : traveltime= 41.17 waitingTime= 10088. speed= 9.74"

mainlane 1 : traveltime= 64.55 waitingTime= 20487. speed= 6.23"

mainlane 2 : traveltime= 33.13 waitingTime= 10519. speed= 12.13

Episode: 3 Rewards: 1019.0481 Bottleneck speed: 1019.0481 out-in flow: -740.0000 Average travel time: 67.9600

----------------------------save model-----------------------------, episode= 3