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55645

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Problem Chosen
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2017
MCM/ICM
Summary Sheet

(Your team's summary should be included as the first page of your electronic submission.)

Type a summary of your results on this page. Do not include the name of your school, advisor, or team members on this page.

Toll plaza has always been the bottle neck of highway. When the road is not so congested, barrier toll only drags the traffic down linearly, however, when the traffic gets heavier, cars suffer not only from tackling with toll booth, but also from competing with other cars.

We modeled toll plaza traffic by decomposing the system into four components.

- The Map (M). Map stands for the vertical view of the toll plaza. A Map is composed by grids in our simulation system. Each grid is a 4.5m (length) * 2.7 (width) road space in reality. In our simulation system, we use numerical matrix to depict map, where 0 is road and -1 is non-road. We can simulate different kinds of plaza designs using different kinds of 0/-1 matrix.
- The Generator (G). Generator is an abstract concept which stands for the total number of cars getting into fan-in area per second. We assume that G composites Poisson distribution.
- The Booth Dispatcher (D). Booth Dispatcher stands for processing ability and strategy of tollbooths. By assigning processing speed to D, we can simulate difference types of toll booth. By assigning different cooperating algorithms to D, tollbooths can cooperate with each other in complex patterns.
- The Car (C). A Car is the basic element of the system and has its own attributes and driving strategy. Each Car has its own real-time location, velocity and acceleration. Each Car has complex driving strategy so that Cars in our system can speed up, break, overtake and even merge into other lanes. By assigning different driving strategies to a Car, we can simulate self-driving cars and man-driving cars.

After building the model successfully, we further designed an evaluation system. The system consists of five Indexes, among them are:

- Traffic through put index which evaluates the efficiency of the fan-in area.
- Average waiting time per length index which evaluates the individual efficiency.
- Accident Index which evaluates the safety level of the fan-in area.
- Construction cost which evaluates the construction spend.
- Composite Cost Index (CCI) which includes all four Indexes mentioned above to make a comprehensive evaluation index for decision making.

With our model and assessment system, we did following researches and got following conclusions:

- We validated our model by comparing its result to real situation. We used two simulation results: traffic-flow to accident index picture and traffic-throughput to individual efficiency. Comparison to reality shows that our model is highly trustful.
- We did research on the influence of self-driving automobiles. We found that when traffic flow is very heavy, self-driving automobile can still keep a higher throughput than man-driving cars, however, self-driving cars causes more accidents than man-driving cars, probably because self-driving algorithm is still premature.
- We did research on different merging patterns. We found that lanes merging to the left will reduce accident index. By convention, cars take over on the left side, this may cause the advantage of left-side merging.
- We did research on ETC roads especially and found that, if we don't set ETC lane aside, they will cause a lot of troubles, so if not afforded to build a separate lane for ETC, we had better remove it.
- We did research on size and shape of the plaza and found that shorter length will cause more accidents. Also, longer fan-in area brings bigger traffic throughput. If affordable, make the fan-in area longer in length will help a lot.
- We did research on ratio of types of tollbooth and found surprisingly, that overall, different types of tollbooth bring little difference.

We also did sensitive analysis at the end of our research.

Last but not the least, because of limitation of time, we are not able to complete everything. We concluded our future works and will promote our system in the future.

Dear New Jersey Turnpike Authority,

We are highly honored to write to write to you to discuss about our research and analysis on the toll plaza designing. New Jersey Turnpike Authority operates two main highways and both of them profit from toll. Near New York, some of your toll plazas are causing a lot congestions as you know. We believe that our finds are valuable to your decision making and toll plaza redesigning.

We made a toll plaza traffic simulation system—Free Map Style road simulation system. The system consists of a Generator, a Map, a Toll Barrier and Cars. Validation test shows that our model is highly trustful.

According to our simulation, there are a few suggestions that we can present for you to consider.

- As there are more and more attention and concern about self-driving automobiles, we did research on the influence of self-driving automobiles on your toll plaza. We found that when traffic flow is very heavy, self-driving automobile can still keep a higher throughput than man-driving cars, however, self-driving cars cause more accidents than man-driving cars, probably because self-driving algorithm is still premature. If you want to raise throughput of the toll plaza, automobiles are welcome. However, you should be careful about them as they may bring you more troubles.
- We did research on different merging patterns. We found that lanes merging to the left will reduce accident index significantly. The reason is that, by convention, cars take over on the left side. Some of your fan-in areas merge to the right and we suggest you consider changing them.
- We did research on ETC roads especially and found that, if we don't set ETC lane aside, they will cause a lot of troubles, which means if we cannot afford to build a separate lane for ETC, we had better not build an ETC at all.
- We did research on size and shape of the plaza and found that shorter length causes more accidents. Also, longer fan-in area brings bigger traffic throughput. If fund allows, we suggest you make the fan-in area longer in length.
- We did research on ratio of types of tollbooth and found surprisingly, that overall, different types of tollbooth bring little difference. Since automated booth will save salary in longer term, we suggest you apply automate booth as much as possible.

All of these suggestion is made out by our Free Map Style road simulation system. This system is still under development, but it has already got considerable commercial value. If you are interested in the system, we are welcome for business.

Thanks for your time and hope that we can have a happy conversation in the future.

From team 55645
24th, Jan, 2017

Contents

1 Restatement of the problem

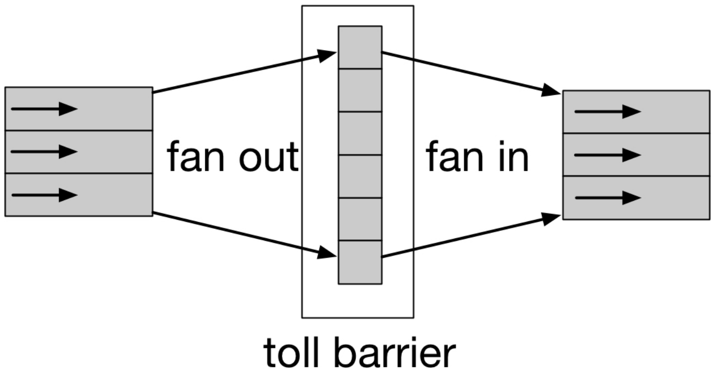

Figure 1: Top view of a toll plaza

Figure 1 is a vertical look of a toll plaza. Barrier toll is the row of toll booth placed across the high way. Considering that cars are going more slowly than usual when passing toll plaza, there are often more tollboothes than coming lanes as shown in the picture. Cars will fan out then fan in when going through the toll plaza. In this research, we care only about the part after (include) the barrier toll, namely, the fan-in area including toll barrier.

There are a few attributes of the plaza that we especially care about. Among them are:

- The shape of the plaza
- The size of the plaza
- Merging pattern of the area

There are a few important considerations that are included in our model, among them are:

- Accident prevention
- Traffic throughput
- Individual efficiency
- Land and road construction cost

There are a few conditions that should be considered separately, among them are:

- Light and heavy traffic
- Self-driving or man-driving car
- Different kinds of booth (man-staffed, automated and ETC)

2 Assumption and justification

Assumption and justification serves our later modeling. With these assumptions, we are able to simplify the reality and at the same time, keep the essence. We made the following assumptions:

2.1 Map

Map are divided into grids. Each grid is

$$4.5m(length) * 3.7(width)m$$

according to our research. We define a grid-length (gl) is $4.5m$. All our system parameters are defined according to gl, including car velocity, car length etc.

2.2 Generator

Car appearances in Generator is considered independent events. Furthermore, we assume that the number of appearance in single generator composites Poisson distribution.

2.3 Tollbooth

Service type of tollbooth is divided into three types: automated tollbooth, man-staffed tollbooth and ETC tollbooth. We design their average service time according to research.

Furthermore, in oder to make it real, we assume that service time of tollbooth composite normal distribution. Different kinds of tollbooth has different parameters.

2.4 Car

In our system, we assume cars are identical with each other in terms of length, max velocity, and breaking. Since time is limited, it is justifiable for us to do such simplification.

However, we still make a huge difference between self-driving car and man-driving car. They have same automobile performance but different driving strategies and cooperating pattern. For example, auto-driving auto-mobiles in our system have sensors to detect the exact velocities and locations of cars around it. With this ability, automobiles can drive and cooperate in a different way from human being.

More specifically, the length of our car is 1 grid-length (gl). And acceleration is $1gl/s^2$. Max breaking is is designed to be very big, as big as need. However, acceleration reaches $-3gl/s^2$ (breaking) will be considered dangerous and will be recorded. We use dangerous breaking to evaluate accident index. We will go into details later in following sections.

Last, velocity of our car changes discreetly. This is caused by our simulation granularity. The smallest granularity is a gl. As a result, location change of car is also discrete.

2.5 System

In our system, there is no actual car accident. Accident rate is evaluated by the number and density of breaking over $3gl/s^2$. We assume that dangerous breaking can stand for accident. Accidents on high way are mainly rear-end collisions and rear-end collisions are caused mainly by sudden stop, so it is reasonable.

3 Notation

Our notations are:

Letter	Meaning
D	the set of the ids of cars passed the fan-in area
t_i	the time to drive through the fan-in area for car i
t-	average of t_i over D
Ci	count of sudden stops for car i
C	total sudden stops of cars in D
$Q_{traffic}$	number of cars passed through the fan-in area
l_0	length of a standard fan-in area (450m)
l	length of a fan-in area
B	number of tollbooths
L	number of lines of travel
S	number of grids(in the map of our model) of the fan-in area
S_0	area of a grid
p	the construction cost of a grid's road spreaded over its life time (15 yrs) per 1000 seconds
W	over all estimated benefit of a fan-in area (dollar per 1000 seconds)

4 Free Map Style (FMS) road simulation

Figure 2 is a overall model design of our simulation system. We named our model Free Map Style (FMS) road simulation because our system is able to simulate any map shape and give real time simulation.

We are going to introduce our model part by part.

4.1 Generator

Generator is an imaginary car generating source. Generator is consists of G-source and G-lane as Figure 3 shows. As we only care about the fan-in part of the plaza, we use generator to abstract the traffic before toll barrier (exclude).

The generator consists of G-source and G-lane. G source generates cars by Poisson distribution. And then send generated cars into G-lanes. G-lanes are connected to toll barrier, through which cars will go into fan-in area.

According to our assumption, G-source cars according to Poisson distribution.

$$P_k = \frac{\lambda^k}{k!}e^{-\lambda}$$

Where k is the number of car reaching toll plaza in one second. Lamda is the expected

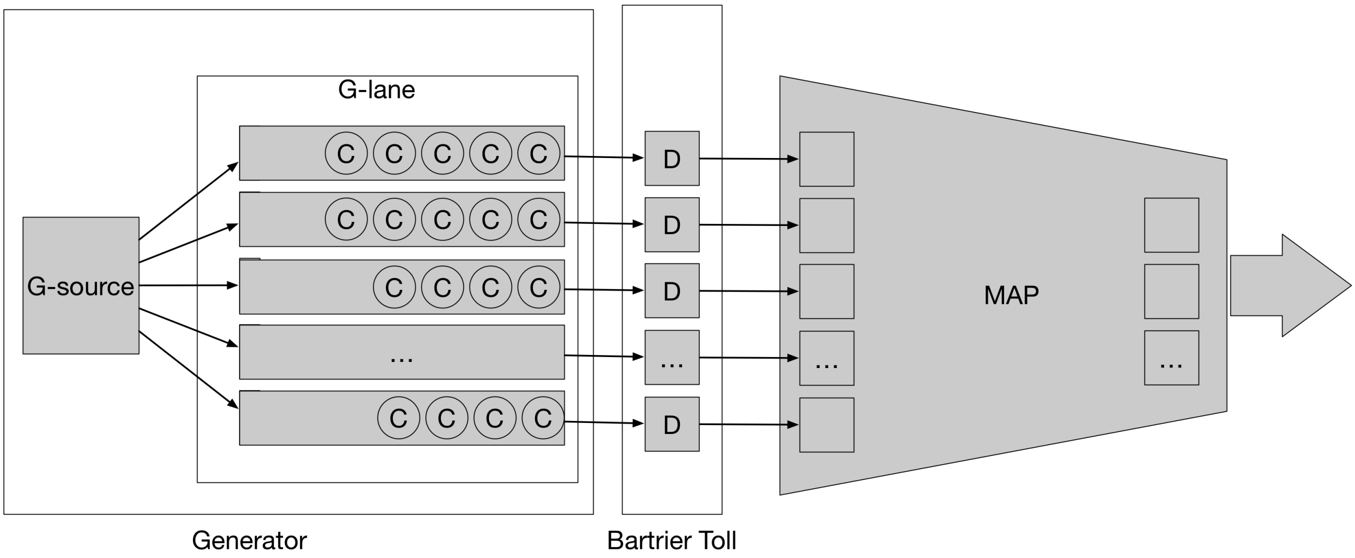

Figure 2: overall view of the Free Map Style (FMS) road simulation model

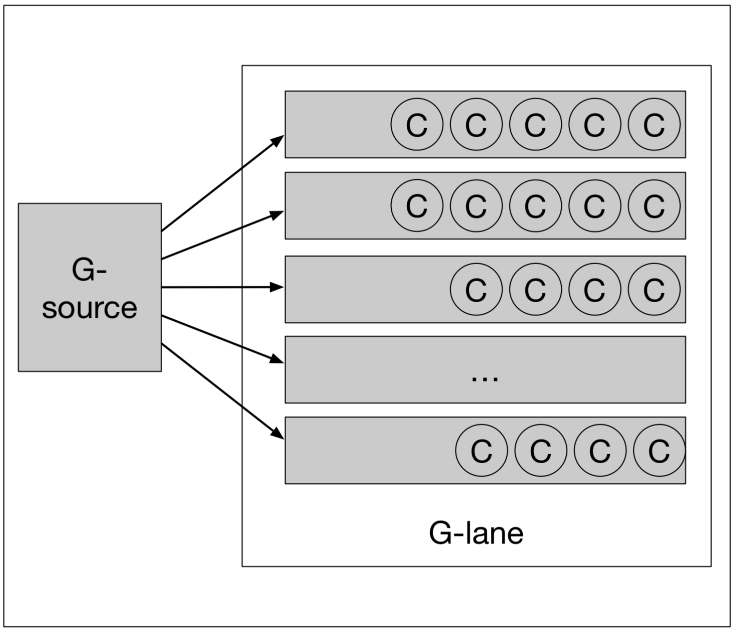

Figure 3: Module of Generator, which is consists of G-source and G-lane

mean number of car reaching the toll plaza. By changing lambda, we can control volume of the traffic, either heavy or light.

After G-source generates cars, it decides which lane cars should be sent into. We have two versions of sending algorithm.

The older sending algorithm, which is call D-one, allocates cars into the shortest waiting lane. If there are lanes that have same length, algorithm will send the car to the lane on the left edge. If use this algorithm, cars will be spread evenly and left side will have slightly and insignificantly more traffic than the right side.

Based on D-one algorithm, we modified our sending algorithm into D-2 algorithm.

The new D-2 algorithm will send cars into lane which looks like a time saver. Namely, the G-source will assess automatically and chooses an optimal lane for the current car. This resembles the choosing and decision making process of a human driver.

4.2 Barrier toll model

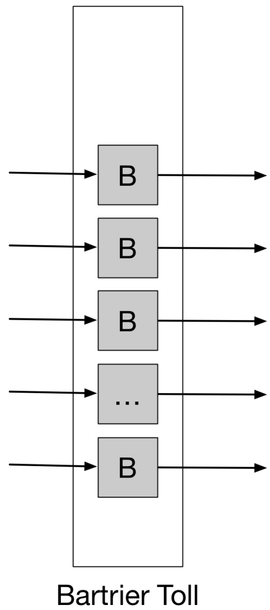

Figure 4: Module of barrier toll

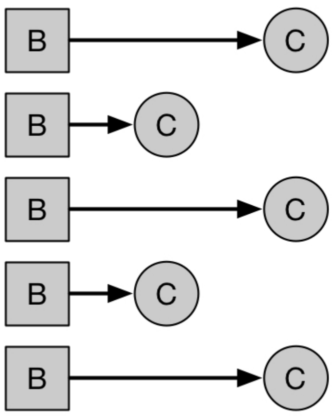

Figure 5: A possibily letting out algorithm

Barrier toll is the part letting cars in the G-lane into the fan-in area. Each B stands for a single toll booth as shown in Figure 4. We modeled the booth into a single and independent working part. A booth accepts cars from Generator and decides when and how to let cars in.

There are all together three types of booth in our system:

- Man-staffed booth which processes each car relatively slow.
- Automated booth which processes each car faster than man-staffed booth.
- ETC booth which processes each car even faster than automated booth. What is more, cars getting out of ETC booth have initial velocity of 6 gl/s while cars getting out of man-staffed and automated booth have no initial velocity

Service time are modeled in normal distribution.

$$f(X) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(X-\mu)^2}{2\sigma^2}}$$

Another exciting thing is, if we model each booth into a separate entity, they can cooperate with each other in a kind of complex way. For example, a booth can let its current car out a bit latter than its neighbor. In this way, two cars will not drive in parallel but in a sawtooth shape as shown in Figure **??**. In this way, cars do not have to compete for road. Such cooperating possibility give us large space for imagination and we are really excited about it.

4.3 Car model

Car is the most important unit of our system. We put most emphasis on our Car model. Our car is able to accelerate, break, taking over, merge from one line into another.

Basic attribution of our CAR model is show below.

Attribute	**Initial**	**Limitation**
Velocity	0	$8gl/s$
Acceleration (speed up)	0	$1gl/s^2$
Acceleration (breaking)	0	-
Self-driving	-	Ture or Flase

Table 1: Attributes of Car

Furthermore, a Car in our system can either be self-driving or man-driving car. They have different driving algorithm which will cause great different in driving patter, cooperating pattern and other performances. Below is the sudo-code of self-driving car algorithm.

self-driving sudo-code

```
# go straight
if (speed_y > gap_f and speed_y <= SPEED_LIMIT)
speed_y <- gap_f;
else if (speed_y >= SPEED_LIMIT)
    speed_y <- SPEED_LIMIT;
else
    speed_y <- speed_y + 1;
# merge into other lane
left_checked <- FALSE;
speed_x <- 0;
if (there is lane on the left) {
    if (gap_fl > gap_f and (car_bl == None or gap_bl > car_bl.speed_y)) { # can merge
        if (merge) {
            speed_x <- -1;
            speed_y <- min(speed_y, gap_fl);
        }
```

```
        left_checked <- TRUE;
    }
}
if (!left_checked and there is lane on the right) {
    if (gap_fr > gap_f and (car_br == None or gap_br > car_br.speed_y)) {
        if (merge) {
            speed_x <- 1;
            speed_y <- min(speed_y, gap_fr);
        }
    }
}
```

We didn't put our man-driving code into the paper considering the limit space. The two algorithms are similar in some degree but still differs from each other in two significant ways.

First, a machine will never feel tired. Man driving car preforms random speed down when driving to simulate the reality. However, auto-driving car will keep a same speed when there is no need to break.

Second, a self-driving car can make use of information collected by sensors. However, these information will not be sensed by human being. For example, the speed of cars around it. While a human being will not choose to merge into another lane when it does not look safe, a self-driving car can calculate and make scientific choice no matter how dangerous it may look like.

It is these advanced features that enables self-driving acts differently from man-driving car.

4.4 Map design

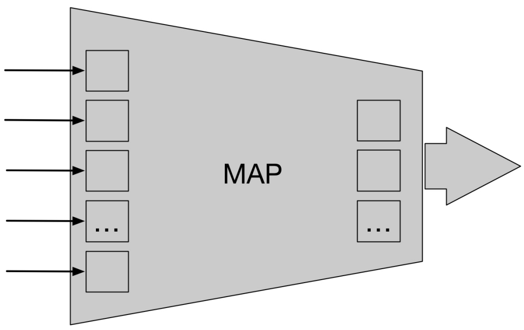

Figure 6: This is a sketch of Map where cars come from B booths and go into L lanes. The figure below is a more detailed depiction of how we store and describe maps in program.

Map is another basic element of our model. Everything happens in a map. In the map, 0 stands for road that car can drive on, but -1 stands for area where car cannot drive on. In this way, we can make a map out of a 0 and -1 matrix. Each grid is a $4.5m * 3.7m$ area.

With this âĂŞ1 and 0 system, we are able to design different kinds of map and test its performance. This give us large space of imagination. We are free to try different shapes of plaza, different ratios of L and B, different booth location, different plaza length etc. This enables us to do research and discuss about every detail of the plaza.

Figure 7 is only an Example map matrix. Real maps are much longer. This map shows a kind of design of toll plaza fan-in area. Cars fan in from nine lanes into three lanes.

On computer engineering aspect, we designed our system interface using csv file. We can

-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
0	0	0	0	0	0	-1	-1	-1	-1	-1	-1	-1
0	0	0	0	0	0	0	0	0	-1	-1	-1	-1
0	0	0	0	0	0	0	0	0	0	0	-1	-1
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	-1	-1
0	0	0	0	0	0	0	0	0	-1	-1	-1	-1
0	0	0	0	0	0	-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Figure 7: Map model depicted in form of matrix

easily design different map in Microsoft Excel using 0 and -1 and then generate csv file separated by English style comma. This csv file then can be recognized by our system and generate virtual maps automatically. Then the map will be tested in our system for further assessment work. This pipeline enables us to do research works on factors easily.

5 Performance measurement system

We developed our own performance measurement system in order to find the best map design and best setting of the system.

There are four indicators in our evaluation system. They are: average waiting time per length, traffic throughput, accident index and construction cost. Using these four indicators, we further developed a composite index called Composite Cost Index (CCI) which is designed to evaluate a toll plaza plan from comprehensive aspects. Using this CCI, we will be able to evaluate a plan from different aspects.

Now we explain the five indexes mentioned above.

5.1 Average waiting time per length index

Average waiting time per length is an Index evaluating the expected waiting time per length to get through the fan-in area. The smaller the Index is, the higher the efficiency. We use per length because maps have different lengths. Use absolute passing time is unfair.

$$\bar{t} = \frac{\sum\limits_{i \in D} t_i}{Q_{traffic}} \cdot \frac{l_0}{l}$$

5.2 Traffic throughput index

Traffic throughput is a index evaluating the car exit number in a certain period of time. The higher traffic throughput index, more cars enter then leave the fan-in area.

$$Q_{traffic} = |D|$$

There is one thing that need to be mentioned. Counter intuitively, according to our result, the higher Traffic throughput is, the lower average waiting time per length index will be. We will go into details of this later.

5.3 Accident Index

In our system, there is no actual accident. Cars are designed to break abruptly if they feel necessary. Cars can break in infinite minus acceleration, however, if we detect minus acceleration bigger than a dangerous level($3gl/s^2$), we count it as an accident. In this way, we will be able to evaluate the safety level of the fan-in area. The higher accident index, there will be more expected accidents.

$$C = \sum_{i \in D} c_i$$

5.4 Construction cost index

Construction is very expensive. When evaluating a building plan, we should take cost into consideration. In our system, cost is mainly calculated by the space of the plaza. The bigger that plaza, the more expensive the plan will be.

It is necessary to mention that, the space of the plaza can be calculated by counting 0s in our map file.

$$P = S \cdot s_0 \cdot p$$

5.5 Composite Cost Index (CCI)

Those above four indexes should have different weights under different situations. If the company is tight in fund, we will give the cost higher weight to emphasis it more. If the company is more considerate about road safety and company public image, we can put more emphasis on safety by changing the weight of accident index.

$$W = k_1 \cdot Q_{traffic} - k_2 \cdot \bar{t} \cdot Q_{traffic} - k_3 \cdot C - P$$

6 Analysis and case study on Free Map Style map simulation system

6.1 Model validation

We have two model validation cases. The first case is quite interesting and also counter intuitive. The higher the road throughput, the more time a car will spend getting through the plaza averagely. It is surprisingly to see that when the whole system efficiency soars, individual efficiency drops. This is quite reasonable actually. When the traffic through get higher, there will be more cars on the road. Individual efficiency decreases when there are more cars on the road.

The other validation is even more convincing. Figure 8 shows the relationship between traffic and average accident per car. This result surprisingly resembles to the reality and also

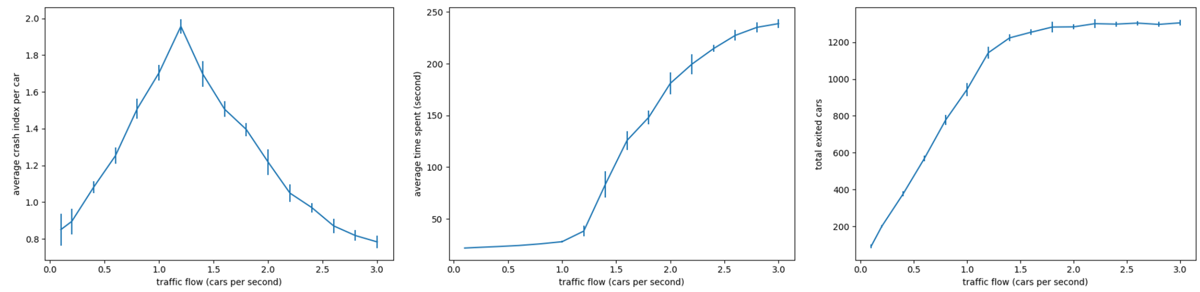

Figure 8: Model Validation

interesting. When there is little traffic on the road, no accident will happen. When the traffic gets heavier, accident rate goes up. However, when the traffic keeps going up, velocity of every single car is dragged down significantly so the accident index is going down. Finally, when the traffic raise to an extent that cars hardly move, there will be no risk and accident for any car at all.

These two validation cases show that our model has the ability to model the traffic in the plaza successfully. This model is trustful. Only then we can do more analysis with the help of the model.

6.2 Size analysis

We compare two sizes of fan-in area in this part. They are different in length: $100gl(450m)and50gl(225m)$.

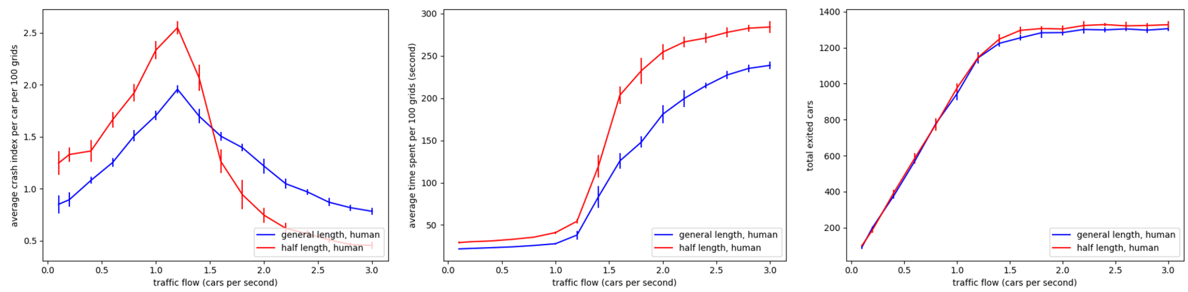

Figure 9: Model Validation

The average speed of cars becomes lower when the length of fan-in area becomes shorter, and there are more likely to crash when traffic flow is in normal size. Drivers need to change lane more rapidly due to the shorter buffer area, which leads to increase of collision.

However, the maximum of traffic flow does not change obviously.

6.3 Merging pattern analysis

1)

For manned cars, there isnâĂŹt obvious difference between the two patterns.

For self-driving cars, before the vehicle flow is saturated, the pattern of 1R1T shows less average collision times, and shorter time in fan-in area. But the road capacity of two patterns are similar.

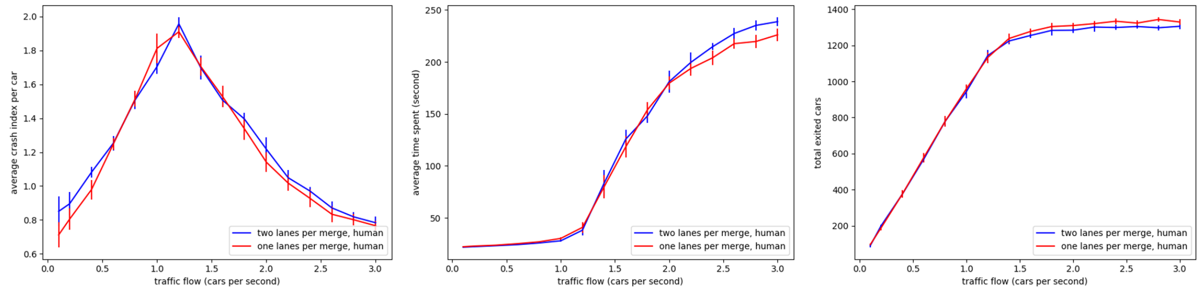

Figure 10: Reduce two roads at a time (2R1T) VS reduce one road at a time (1R1T)

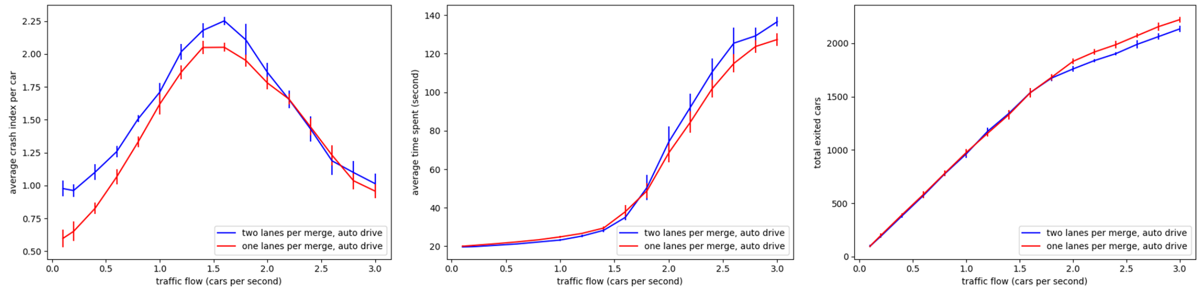

Figure 11: Reduce two roads at a time (2R1T) VS reduce one road at a time (1R1T)

2)

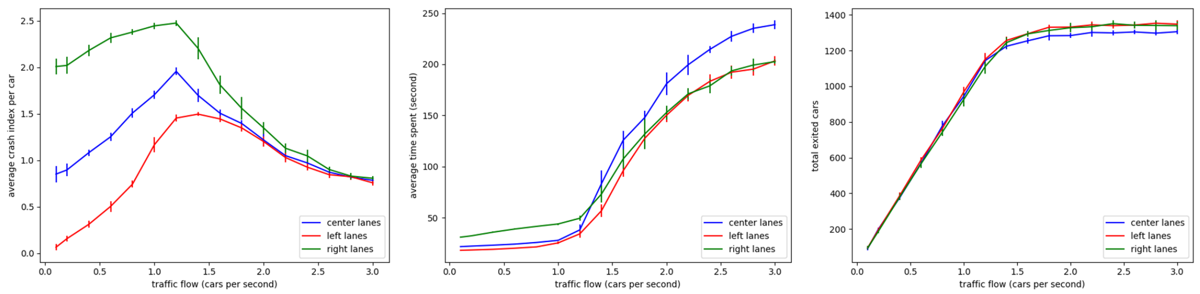

Figure 12: Merge to center lanes (CL = center lanes) VS merge to left side (LL) VS merge to right side (RL)

When traffic flow is low, LL and CL show the lower probability of collision than RL, and LL is the lowest among them. That is because cars give priority to cut to the left lane. Because of the same reason, cars in RL use more time than LL and CL. When traffic flow becomes higher, because of the heavy traffic jam, the result of three patterns are fairly close.

3)

SEP is more likely to have an accident than MIX. Because cars in ETC lanes are much faster than other cars, so it is more difficult to merge.

6.4 Self-driving automobile analysis

We use a certain map to test whether self-driving cars have a better performance than man-driving cars.

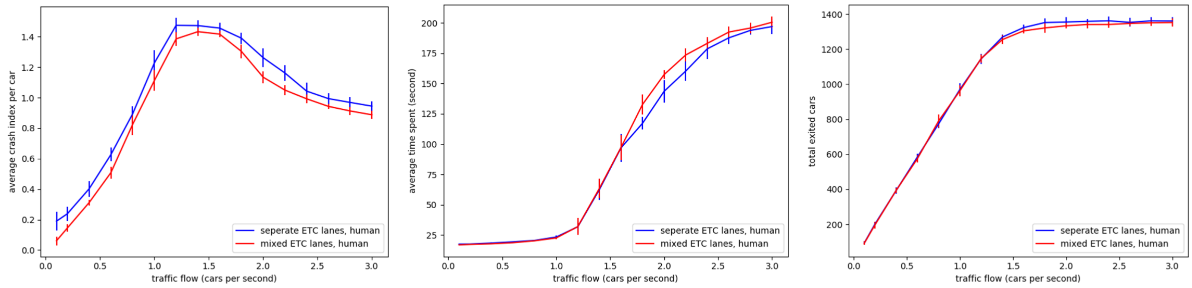

Figure 13: Merge pattern of ETC lanes: ETC lanes mix with other lanes (MIX) VS ETC lanes separate from other roads (SEP)

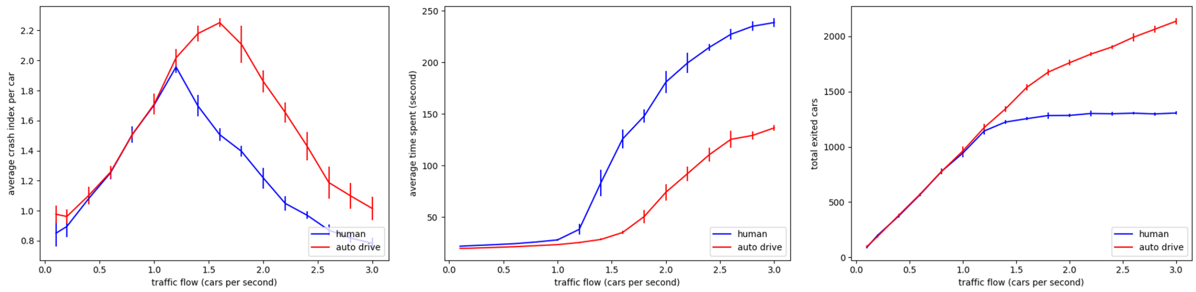

Figure 14: Self-driving automobile analysis

Figure 14 shows that self-driving cars use less time than man-driving cars, and the area can pass more self-driving cars than man-driving cars. Self-driving cars usually have a faster speed and change lane more promptly than man-driving cars, so it is more difficult to cause traffic jams, and self-driving cars can get out of the fan-in area quickly. When traffic flow is bigger than 1.2, the throughput of man-driving cars can hardly become bigger. And just because of the same reason, the probability of collision of self-driving is higher.

6.5 Tollbooth type analysis

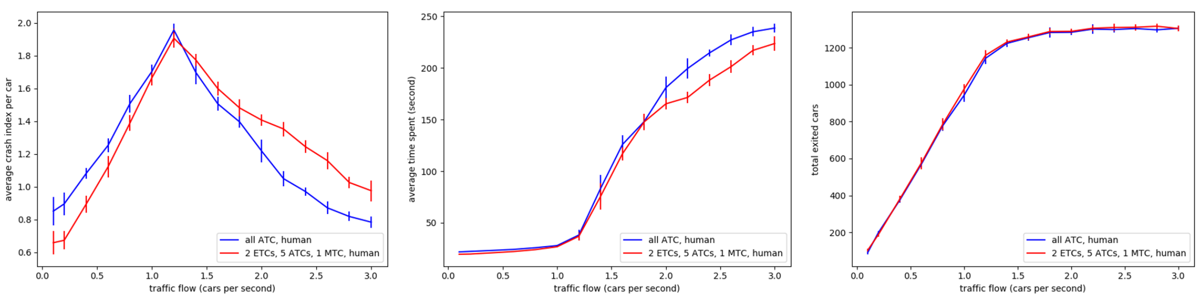

Figure 15: Tollbooth type

(i) All 8 ATCs (Automated Toll Collection Booths) VS (ii) 2 ETCs + 5 ATCs + 1 MTC (Manned Toll Collection Booths)

Assumption: a car spends 1s at a ATC, 5s at MTC, and directly goes through ETC with velocity 3 gl/s at average.

When traffic is low, (i) is more likely to have an accident, and the result is opposite when traffic flow becomes higher.

When traffic flow is very high, (ii) is more efficiently, drivers spend more time waiting on pattern (i).

The road capacity of (i) and (ii) are fairy close.

7 Sensitivity analysis

This model is sensitive to the traffic flow changes when the traffic is not heavy. But when the traffic is very heavy, the output traffic from fan-in area will no longer grow higher. However, average crash index per car will go down when traffic flow grows. Average time spent will also go up dramatically. In this way, we can say our model is sensitive to traffic flow changes: when traffic is light, average crash index per car and $Q_{traffic}$ are sensitive; when traffic is heavy, average crash per car and average time spent are sensitive.

8 Strength and weakness

Since our model is cleared divided into four parts, we discuss the strength and weakness of the system in parts.

8.1 Generator

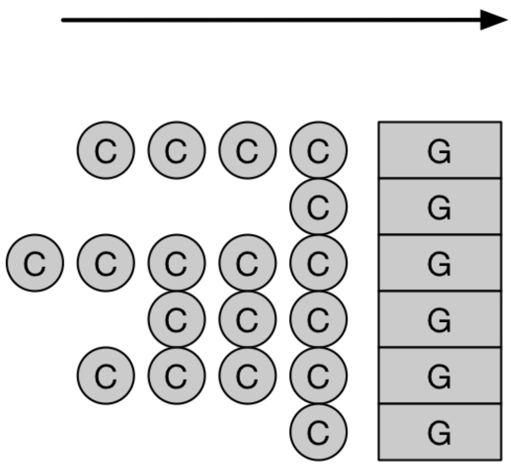

Figure 16: Strength and weakness of Generator

Our generator is rather smart. The generator will generate cars according to Poisson distribution which resembles to the reality very much.

When generator is generating too much car, in another word, there are too many cars trying to jam into booth barrier at the same time, they will wait in a queue. This situation is considered and simulated in our system using queues.

Our generator designed to act as real.

There are also some weaknesses in our Generator. By using Poisson distribution, we assume that each car appearance is independent, which is not often true in the reality.

Our generator send cars into the shortest queue to simulate the reality, however, this does not necessarily happen. Some driver would rather wait for a few minutes than going into another lane (in western country, driver are supposed to stay in their lanes, but in some Asian countries, drivers are free to change lanes as they want.)

8.2 Barrier toll

We modeled each tollbooth as a separate model. Such arrangement empowers our system with such advantages:

First, we can design different barriers with different attributes. We build man-staffed barrier which is slow and automated barrier which is faster and ETC barrier which is not only fast, but can let out cars with initial velocity.

Second, as we modeled a single toll barrier booth, we are able to design smart cooperating algorithm. For example, a toll barrier may let its car out a little bit later than its neighbor. In this way, cars will not go parallel but in a sawtooth shape. Drivers will have a clearer relative position and avoid lane competing, which potentially raise safety index.

However, unfortunately, because of tight time arrangement, we do not have enough time to tackle with booth smart cooperating algorithm. We are excited and motivated to finish this work in the future and see how much this will add to the system efficiency.

8.3 Car model

We are proud to say our car model is highly real. With our simulation, our car is able to change lane, merge lane, overtake, speed up and speed down. The movement of our car is not only decided by its own situation, but also cars around it.

Also, all parameter of the car is designed according to reality, including length, max velocity, acceleration capacity, breaking etc.

However, we did a few assumption which will reduce the accuracy of our simulation.

First,All our cars in the system are identically same in terms of length, velocity and other automobile performances. (We do separate self-driving cars from man-driving car, as this is one of our important considerations.) Second,velocity change discretely in our system. Which means the speed can go up from $3m/s$ to $6m/s$ in an instance. This is cause by the simulation grain size. As a result, location simulation is discrete also.

8.4 Map

On design aspect, out map system is designed to be a completely free system with huge space for innovation. Our map use 0 to stand for road and -1 to stand for non-road. We design $B * length$map with L outlets using matrix composed by 0 and -1.

Because of the special design of our program, we are able to design different maps in Excel and then generate virtual maps automatically and test them in our system. This powerful pipeline enables us to test different maps with ease.

There are still room for us to improve the system. We did not take lane barrier into consideration. By road barrier we mean those barriers on road to separate lane from lane. We will upgrade our system in the future to make this possible.

9 Conclusion

We modeled toll plaza traffic by decomposing the system into four components. Generator, Map, Booth Dispatcher and Car.

After that, we made a evaluation system consists of traffic throughput per length, average waiting time per length, accident index, and construction cost. We further developed a Composite Cost Index (CCI) to make comprehensive evaluation.

Using our model and evaluation system, we drew the following conclusions.

We validated our model by comparing its result to real situation. We used two simulation results: traffic-flow to accident index picture and traffic-throughput to individual efficiency. Comparison to reality shows that our model is highly trustful.

We did research on the influence of self-driving automobiles. We found that when traffic flow is very heavy, self-driving automobile can still keep a higher throughput than man-driving cars, however, self-driving cars causes more accidents than man-driving cars, probably because self-driving algorithm is still premature.

We did research on different merging patterns. We found that lanes merging to the left will reduce accident index. By convention, cars take over on the left side, this may cause the advantage of left-side merging.

We did research on ETC roads especially and found that, if we do not set ETC lane aside, they will cause a lot of troubles, so if not afforded to build a separate lane for ETC, we had better remove it.

We did research on size and shape of the plaza and found that shorter length will cause more accidents. Also, longer fan-in area brings bigger traffic throughput. If affordable, make the fan-in area longer in length will help a lot.

We did research on ratio of types of tollbooth and found surprisingly, that overall, different types of tollbooth bring little difference.

10 Reference

Merge pattern of ETC lanes: ETC lanes mix with other lanes (MIX) VS ETC lanes separate from other roads (SEP)

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