# How to design a traffic circle

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## Abstract

We built several models in hopes of minimizing the time delayed in traffic circles in this paper. We divide our models' construction process in three steps.

Firstly, by analysing the problem, we concluded that the time delayed in traffic circles is in direct proportion to traffic flow.

Secondly, we built the capacity-estimated model based on probability theory. In this model we solved the capacity of unsignalized and signalized traffic circles respectively, and finally obtained their capacity functions. Then by calculating with the functions, we concluded that signalized traffic circle is required when the numerical value of traffic flow is larger than the unsignalized circle's capacity. Compared with the limitedness of unsignalized traffic circle, we suggested that the signalized traffic circle is more efficient, that is to say that the time delayed in the signalized circles is less than which delayed in the unsignalized circles.

Thirdly, on the basis of the result of our first model, we established the traffic flow model. In this model our task was to obtain the relation between the time of green phase and red phase. The result represented that the duration of green night should be longer than red night.

Fourthly, to calculate the cycle time of traffic lights, Webster Formula was adopted as we want to minimize the average delay time.

Finally, we established queueing theory model to calculate the average waiting time of traffic at intersections. The effect of stop sign,yield sign and traffic lights were considered in this model.

Our suggested solution includes a Technical Summary , which can explain to a traffic engineer how to use our model to choose the appropriate flow-control method for any specific traffic circle.

# Contents

# 1 Introduction

An intersection is a meeting place for vehicles, traffic circle is widely used at intersections. Its characteristics are that all the drivers drive counterclockwise in the circle, vehicles come from different feeder highways gather together in the circle and are driven toward the same direction until they exit the circle. Because of its characteristics, traffic circles can save a large number of traffic police, ease the traffic pressure and beautify the city. Traffic circles have been reported to be very useful in controlling vehicular traffic at road intersections[1].

In the past, intersections with traffic circles are unsignalized. But with the increase of traffic flow, shortcomings of these unsignalized traffic circles are becoming more and more obvious. How to make traffic circles more efficient？ Then signalized traffic circles appeared. If we know the capacity of the circle, and when traffic flow of the circle is more than its capacity , signalized traffic circle is required. When traffic circles are signalized by traffic lights, it is also necessary for us to set the cycle time of traffic light. Thus vehicles come from different directions can easily enter and exit the circle. The circle's efficiency is raised.

Time is money, nobody likes wasting time in waiting. High efficiency of traffic circles is often regarded as a symbol of a city's development. So how to make the efficiency of traffic circle higher is our aim. To reach our aim, several models are built to determine how best to control traffic flow in, around, and out of a circle in this paper.

# 2 Restatement of the Problem

As a traffic circle has multiple feeder highways, drivers from different feeder highways should decelerate while driving in the circle. Because of the deceleration, traffic jams could easily occur when traffic flow is too heavy.

According to actual situations， there are two kinds of traffic circles: signalized and unsignalized. To solve the problem of heavy traffic flow, it is necessary to calculate the capacity of traffic circle. We obtain the capacity of a traffic circle by using the method of possibility theory. Then based on the capacity of the circle, we can decide if there is necessity to install traffic lights.

When traffic lights are installed, the time of green phase and red phase is the main factor influencing traffic flow. How to determine the time of green phase and red phase? We approached the problem by mathematically analyzing the traffic flow in a traffic circle.

We also developed the computer simulation which modeled the traffic flow in a traffic circle. We use our simulation to learn the average time of delayed in the models we built in this paper.

# 3 Conventions

This section defines the basic terms used in this paper.

## 3.1 Terminology

- **Weaving sections:** A weaving section is a place where several traffic flows can converge and diverge in a short distance.

- **Weaving Point:** A point where the traffic flow circling the circle weave with the traffic flow going into the circle.

- **Conflict Points:**A point where the traffic flow circling the circle have conflicts with the traffic flow going out of the circle or the traffic flow going into the circle.

## 3.2 Variables

We will define the following variables here as they are used widely throughout our paper.

**Variables in section 5.1:**

- $Q$ refers to the numerical value of traffic flow.

**Variables in section 5.2:**

- $x$ refers to the spatial measure on the considered link.
- $t$ refers to the time cost.
- $r$ refers to the interior radius shown in figure 5.3.
- $R$ refers to the exterior radiusshown in figure 5.3.
- $H$ refers to the length of a lane.
- $T$ refers to the cycle of traffic light.

**Variables in section 5.3**

- $x_{xy}$ refers to the distance from Node $x$ to Node $y$.
- $v$ refers toordinary speed of his car.
- $t$ refers to the time the man has been away from home.

Additional variables are made to simplify analysis for individual sections. These variables will be discussed at the appropriate locations.

# 4 Assumptions

The following assumptions are made about designing a traffic circle in this paper. Additional assumptions may be defined later, but will be confined to a particular section.

- There are only vehicles on the roads, and each driver obeys the traffic rules strictly. With this assumption, pedestrians and bicycles needn't to be considered in our model. And because all the drivers are disciplined, there isn't overtaking on the roads.

- A traffic circle and the lanes in it are concentric circles. In some cities, traffic circles and the lanes in them are ellipses, such as at the Victory Monument in Bangkok. It is obviously that intersection angle in a circle is constant,

- Each road that links to traffic circles is an unlimited extension of a straight line.we assume that the roads are so long that traffic jams happened on these roads won't have impact on other roads.

- The consistency and similarity of the drivers. We assume that all the vehicles have the same velocity and the distance between any two vehicles are the same.

- When driving in the traffic circles, drivers in different directions have the same probability to choose which direction they will turn in. To make our research uncomplicated, Characteristics are ignored in this paper.

- The process of Vehicles' stopping and accelerating is instantaneous . When traffic light turns red , drivers can stop their vehicles immediately . As we know, when traffic light turns red, there will be a reaction time for drivers to make the decision of stopping their vehicles.

# 5 Problem Analysis

Figure 5.1 Shows the characteristics of traffic flow in traffic circle:

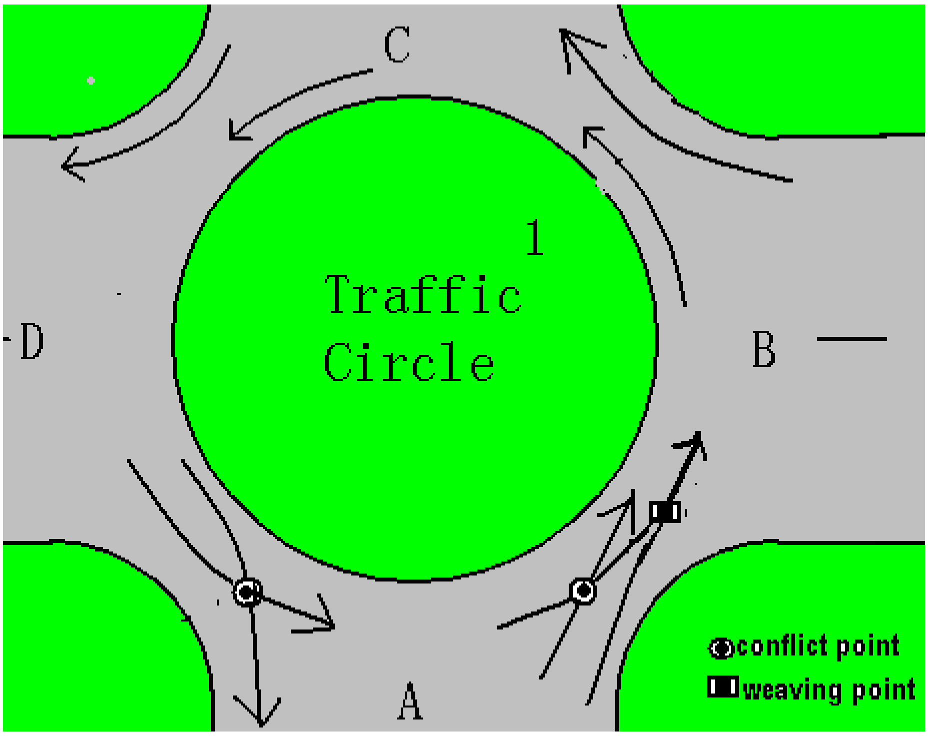


Figure 5.1: Characteristics of traffic flow in a traffic circle.

From figure 5.1, we can see several conflict points and weaving points in the circle. The traffic flow circling the circle could have conflicts with both the traffic flow going out of the circle and the traffic flow going into the circle. Locus of them intersects like "X", the intersections are so called conflict points. And there is also possibility that the traffic flow circling the circle could weave with the traffic flow going into the circle. Locus of them intersects like "Y", which is so called weaving point.

According to reality, when traffic flow is not very heavy, drivers at the conflict and weaving points can take adjustment measures themselves to keep the smooth of the circle. The time delayed in the circle is little. But when traffic flow is heavy, drivers' adjustment can't help. Then a traffic jam would occur, and the time delayed in the circle will increase. As our goal is to minimize the time delayed in the circle, it is necessary for us to calculate the capacity of a traffic circle and determine how to control traffic flow in, around, and out of the circle. Based on these analysis, we can build and improve our models.

# 6 Details of the Model

From the analysis above, we build our models step by step.

## 6.1 Capacity-estimated Model based on Probability Theory

As early as the 1980s, engineers such as Kimber(1980), Troutbeck(1990), Brilon and Stuwe(1990) have suggested different capacity formulas for traffic circles on the basis of the data collected at the traffic circles. More than twenty years has past, with the development of the world, the number of vehicles is increasing, and the number of lanes within traffic circles is becoming larger, too. For example, former traffic circle is usually designed with only one lane, what is not easy for vehicles in the circle to exit. But nowadays the size of traffic circle becomes larger(at least with two lanes). So using former capacity formulas directly in the study of today's traffic is improper.

As we know, former traffic circles are usually unsignalized, which means drivers should adjust their vehicles by themselves to keep the smooth of the circle. Unsignalized traffic circles are only applied to the situation in which traffic flow is not very heavy. Nowadays signalized traffic circles are common. In order to get the proper formulas for today's traffic circle, we should analyse the both kinds of traffic circles.we suggest our method on the basis of Probability Theory.

### 6.1.1 Unsignalized traffic circles

We begin our research by analysing the traffic circle in figure 6.1:

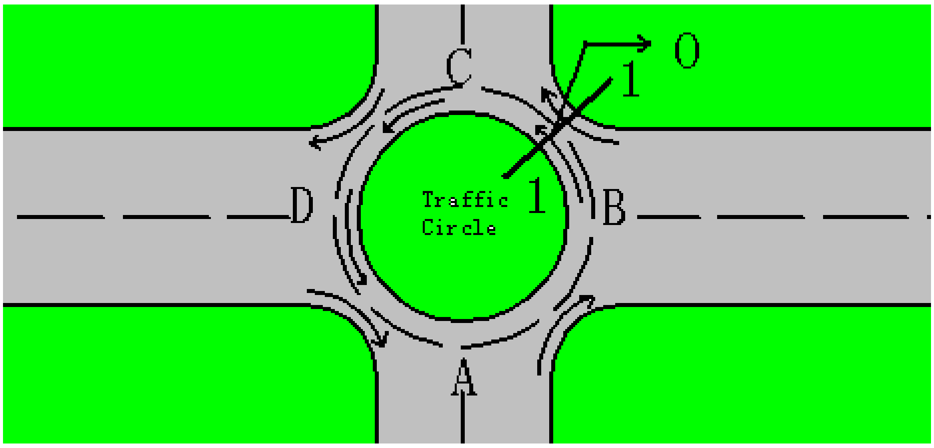


Figure 6.1: This figure shows the unsignalized traffic circle we study in this model. There are two lanes in the circle, and its feeder highways are crossed.

It is easy to know that vehicles come from each feeder highway will have three choices: turn left, turn right, and go straight. Since the traffic circle discussed here has two lanes, drivers can turn right free. Thus the flow of point $O$ in figure 6.1 can be stated as( to make our model easy, we assume drivers in different directions have the same possibility to choose which direction they will turn in)

$$Q_O = Q_{Bs} + Q_{Bl} + Q_{As} + Q_{Al} + Q_{Dl} = 2Q_s + 3Q_l$$

where $Q_S, Q_l$ refer to the numerical value of going-straight flow and left-turning flow.

According to our assumption, we have

$$Q = 4(Q_r + Q_l + Q_s) = 2Q_O + 2Q_r$$

where $Q_r$ refers to the numerical value of right-turning flow.

Set $$Q_r = Q \cdot p$$

where $p$ refers to the percentage right-turning within all the turnings.

we can obtain $$Q = \frac{2Q_O}{1-2p}$$

where $Q_O = \dfrac{3600}{t_i}$. Finally, we can get the function of unsignalized traffic circle's capacity

$$Q = \frac{7200}{t_i(1-2p)} \cdot \frac{3l}{2l+30} \cdot \beta$$

Where $t_i$ refers to the time headway between left-turning and going-straight vehicles, and $l$ refers to the length of weaving section, $\beta$ refers to the uneven coefficient of vehicles' distribution.

By calculating with the function above, we can obtain the capacity of any specific traffic circle. Unsignalized traffic circle plays an important role in traffic only when the numerical value of traffic flow is less than its capacity. The usage of unsignalized traffic circles is limited, that's why unsignalized circles are disappearing nowadays. We can consider the choice of signalized traffic circle when the numerical value of traffic flow is larger than its capacity.

### 6.1.2 Signalized traffic circles

When the traffic circle is signalized at the entrance of intersection, vehicles have to be stopped when traffic light turns red, thus vehicles in other directions can exit the circle easily. The signalized traffic circle we studied is showed in figure 6.2.

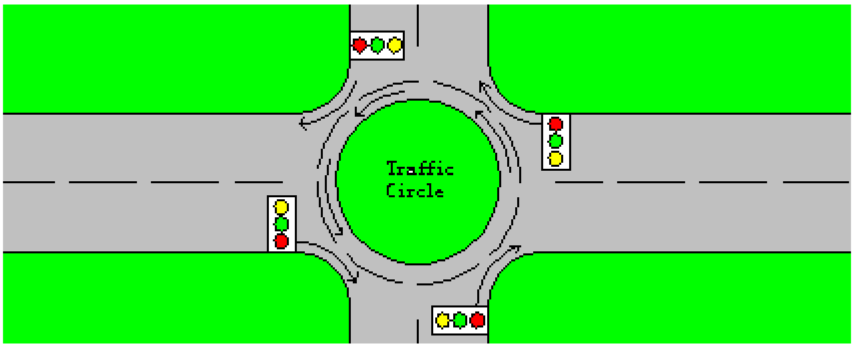


Figure 6.2: A type of signalized traffic circle.

From figure 6.2, we can know that there are right-turning vehicles, left-turning vehicles, and straight-going vehicles in the circle.

As the traffic circle has two lanes, a lane of them can be used for only right-turning. It is obvious that right-turning vehicles is free from the controlling of traffic lights. Then the capacity of right-turning way is

$$Q_r = \frac{3600}{t_r} = Q \cdot p$$

Where $t_r$ refers to the minimum of time headway.

Besides the lane for only right-turning, the inside lane is for left-turning and going-straight vehicles. We assume the cycle of traffic light is T, and $t_r, t_g, t_y$ refer to time of red, green, and yellow light respectively . Then the function of the capacity of inside lane is

$$Q_{ls} = \frac{3600\varphi_s\left[\left(t_g - t_1\right)/t_s + 1\right]}{T}$$

Where $t_1$ refers to the time a vehicle costs from starting to cross the stop line, $t_s$ refers to the minimum time headway of continuous straight-going vehicles, and $\varphi_s$ refers to the coefficient of correction.

With the method used and functions obtained in section 6.1.1 and 6.1.2, we can also obtain the function of capacity in other more flexible situations. With the functions obtained, we can determine the choice of traffic circle. From the two circle's scope of application, it is obvious that the signalized circle is more efficient. OK, let's choose signalized circles, but how to decide the cycle of green phase and red phase? We will build models below to solve this problem.

## 6.2 Traffic Flow Model

Traffic flow can be considered as water flow at the macro perspective. So building traffic flow model is an important way to analyze traffic problems. Using the knowledge of Fluid Mechanics we build the traffic flow model.

Figure 6.3 shows the traffic circle we study.

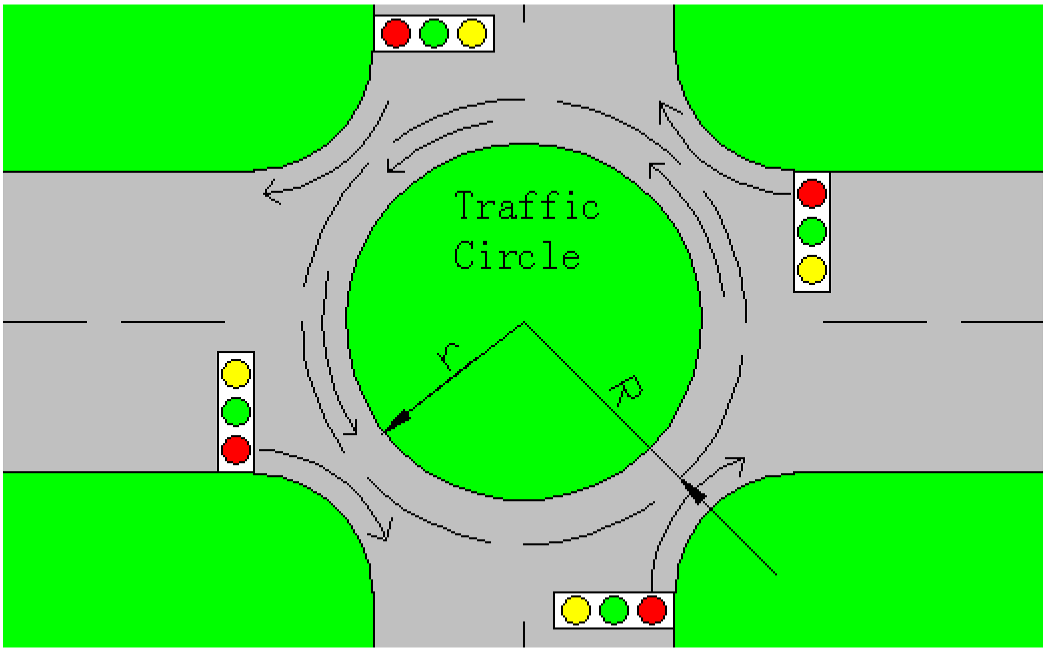


Figure 6.3: The traffic circle we study in traffic flow model.

In traffic flow thoery ,we have following equations:

$$q(x,t) = u(x,t)\rho(x,t)$$

Where $\rho(x,t)$ refers to the number of vehicles on per unit length of road at a time, $q(x,t)$ refers to the number of vehicles passing a observation site in per unit time, and $u(x,t)$ refers to a vehicle's velocity.

According to reality, vehicles' velocity $u(x,t)$ always decrease as traffic density

$\rho(x,t)$ increase.When there is no other vehicles in front, a vehicle will drive at its highest velocity, i.e. if $\rho(x,t)=0$ , $u=u_m$ (maximun value ).When the traffic density *is* too high ,the traffic flow cannot go straight, i.e. if $\rho=\rho_m$ , $u=0$ , set

$$u=u_m\left(1-\frac{\rho}{\rho_m}\right)$$

combined with $q=u\cdot\rho$ we have

$$q=u_m\rho\left(1-\frac{\rho}{\rho_m}\right)$$

Now define the variable $x$ the position of a vehicle as the coordinate system, as shown in figure 6.4 .

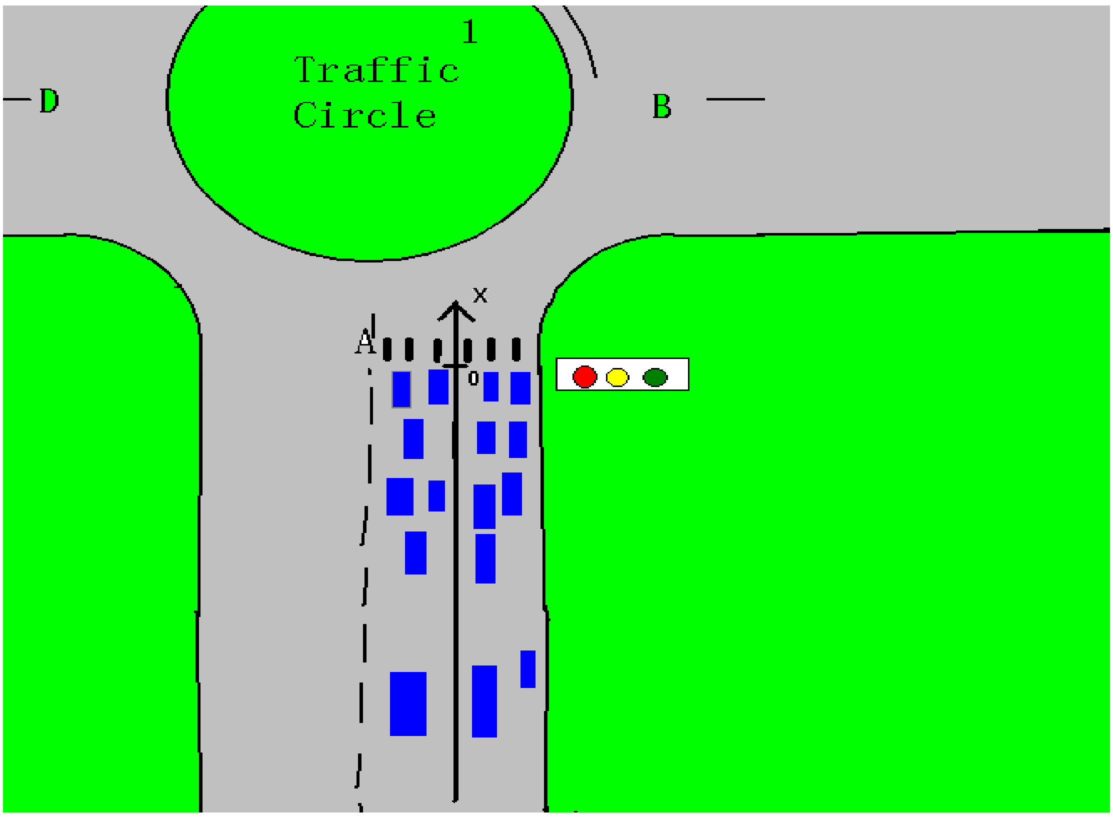


Figure 6.4

At the beginning (when $t$=0), the density of vehicles is $\rho_0$ (const). When traffic light turns to red ( $0\le t\le\tau$ ), vehicles in front of the traffic light stop immediately, then the density of vehicles in front of the traffic light is $\rho_m$, which is the biggest density. Since the change between red and green phase is instantaneous， there is a jump in the characteristic line of vehicles' density (figure 6.5(2)).

Set $x_{sl}(t)$ as the numerical value $\rho_0$

according to Equation of interrupted traffic flow[2].

$$\frac{dx_{sl}}{dt_i}=\frac{[q]}{[\rho]},\text{where}\,[\rho]=\rho_m-\rho_0,[q]=q(\rho_m)-q(\rho_0)$$

from $q=u_m\rho\left(1-\frac{\rho}{\rho_m}\right)$ we have

$$q(\rho_m)-q(\rho_0)=-\frac{u_m\rho_0(\rho_m-\rho_0)}{\rho_m}$$

Therefore
$$\begin{cases}\frac{dx_{sl}}{dt}=-\frac{u_m\rho_0}{\rho_m}\\ x_{sl}(0)=0\end{cases}$$

Solving for the ordinary derivation equation above, we obtain

$$x_{sl}(t)=-\frac{u_m\rho_0}{\rho_m}t$$

When $t=\tau$, traffic light turns to green, drivers start driving(figure 6.5 (3)).

When $t>\tau$， $x_1(t)$ refers to the position of the vehicle at the end of vehicles queue.

For $t'=t-\tau$， function of vehicles' initial density can be

$$f(x)=\begin{cases}\rho_m,x_{sl}<x<0\\ 0,0<x<x_{sr}\\ \rho_0,x<x_{sl},x>x_{sr}\end{cases}$$

For $x_{sl}<x_0<0$， from $\varphi(\rho)=\frac{dq}{d\rho}=u_m\left(1-\frac{2\rho}{\rho_m}\right)$, we have

$$\varphi(f(x_0))=-u_m$$

on the line of characters $x=u_mt'+x_0$， density function $\rho(x,t')=0$。

For $x_0\to 0$， we get

$$x_1(t)=-u_m(t-\tau).$$

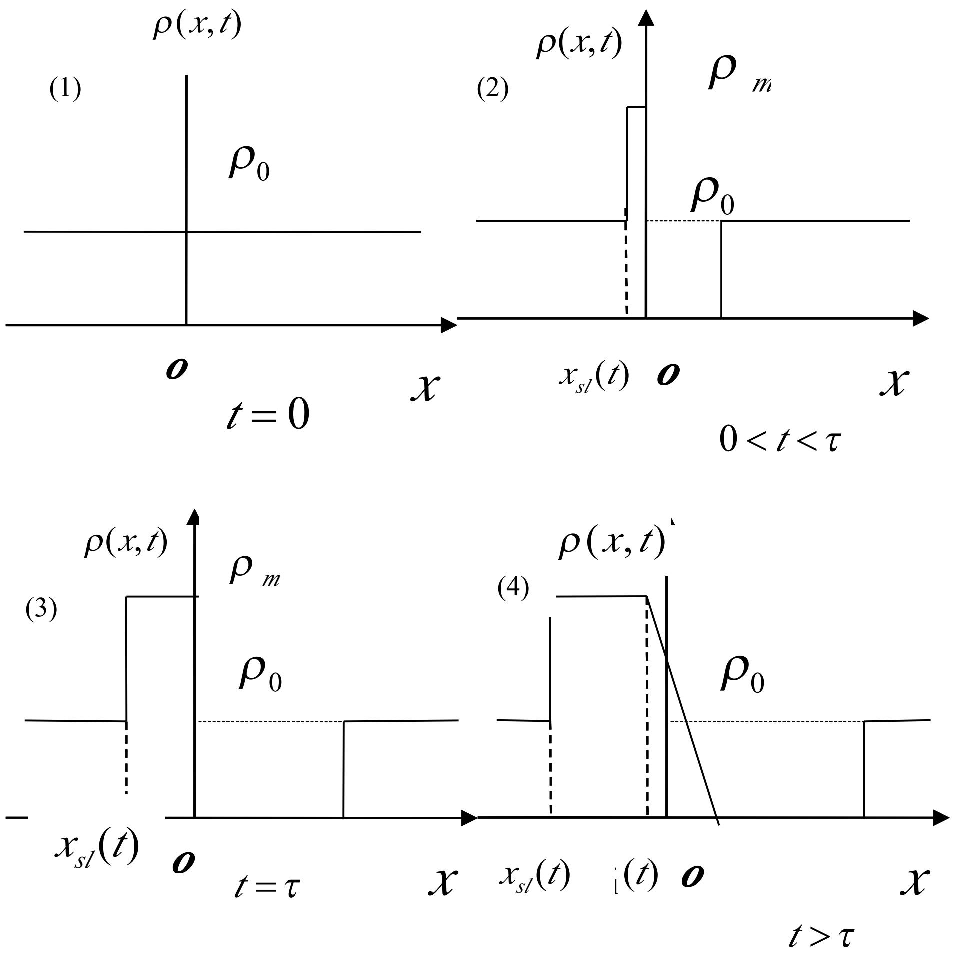


Figure 6.5

Traffic jam is eliminated when

$$x_{sl}(t_d) = x_2(t_d).$$

according to $x_{sl}(t) = -\frac{u_m \rho_0}{\rho_m} t$, $x_1(t) = -u_m(t-\tau)$ we have

$$u_m(t_d - \tau) = \frac{u_m(\rho_m - \rho_0)}{\rho_m} t$$

Solving the equation above, we can get

$$t_d = \frac{\rho_m}{\rho_m - \rho_0}\tau$$

which means at the time $t_d = \frac{\rho_m}{\rho_m - \rho_0}\tau$, 。

It's obvious that the traffic jam will be eliminated before the traffic light turned green,i.e. the lasting time of green light

$$t_g \geq \frac{\rho_m}{\rho_m - \rho_0}\tau$$

Before the traffic light turns red ,the vehicles should arrive at or pass the next intersection .Hence we have

$$t_g \geq \frac{\frac{\pi}{2}(R+\frac{H}{2})}{u_m}$$

The ratio maximum between green phase and red phase

$$t_g + \tau = T$$

## 6.3 Methods to control treaffic circle with signal

### 6.3.1 Cycle Length

Based on the Webster formula

$$V_0 = (1.5L+5)/(1-Y)$$

Where $V_0$ refers to the cycle of signal. L refers to the total loss of time. Y refers to the traffic flow ratio at intersections, and Y takes the following form

$$Y = \sum_{i=1}^{n} y_i$$

Where $y_i$ refers to the traffic flow ratio at NO.i phase of the critical lane. While $y_i$ takes the following from

$$y_i = q_i \times S$$

where S refers to the saturated flow at NO.i phase of the critical lane.

### 6.3.2 Split

In traffic flow model,we mentioned the equation

$$t_g \geq \frac{\rho_m}{\rho_m - \rho_0}\tau$$

Before the traffic light turns red ,the traffic should have arrived at or passed the next intersection .Hence we have

$$t_g \geq \frac{\frac{\pi}{2}(R - \frac{H}{2})}{u_m}$$

$$t_g + \tau = T$$

### 6.3.3 "Green channel"Model for offset

To study the offset ,we consider a car driver at Node A.Now he leaves Node A and travels around the circle while obeying all the traffic signals . He will arrive at Node A at last(figure6.6).

Assumptions made in this section:

- he leave Node A just as traffic light at Node A turned green.
- The phane of traffic light at Node A has already be given.

then we analyze how to arrange phases of lights at other nodes so that the man can get home the fastest.

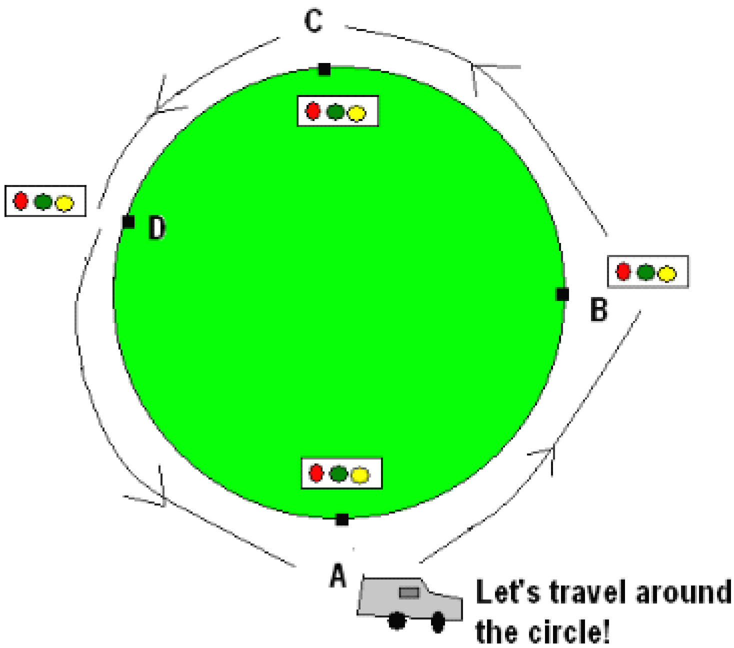


Figure 6.6

If we set a green way for the man,then the time the man arrive at a node ,the traffic light there should be green or close to the end of red light .That's the reason this model is called "Green Way" model.

Now, it's easy to know that the man will arrive at Node B at the time

$$t_B = \frac{x_{AB}}{v}.$$

Mark $t_B$ in figure 6.7, so that we can understand it better. In figure 6.7, X-coordinate stands for the distance from Node A,and Y- coordinate stand for the time the man has been away from Node A.The signal cycle has been marked on the left side of the figure.

If we draw a line passing（0，0）with slope 1/v (line 1 in figure 6.6) ,then the Y - coordinate of its intersection with line BB’ is $t_B$. Then from the points those are the end of BB’ green phases or red phases, we choose one that is the most close to ( $x_{AB}$ , $t_B$ ).

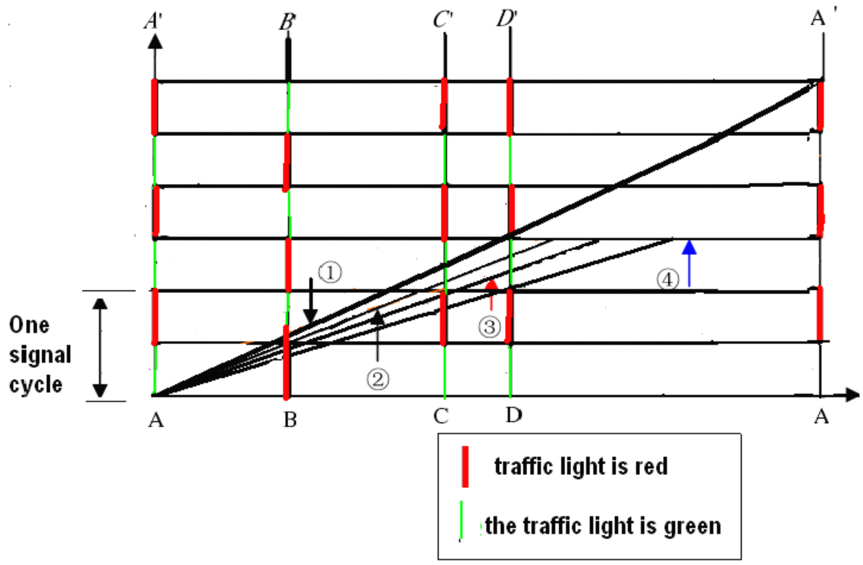


Figure 6.7

## 6.4 Average waiting time estimation based on queueing theory using Jackson Net

Using the theory of queueing, we establish the Jackson Net Model of single service desk. From this model,we put forward the formula for calculating the average waiting time of tracks. In this model traffic circle can be simplified to a network as shown in figure 6.8.

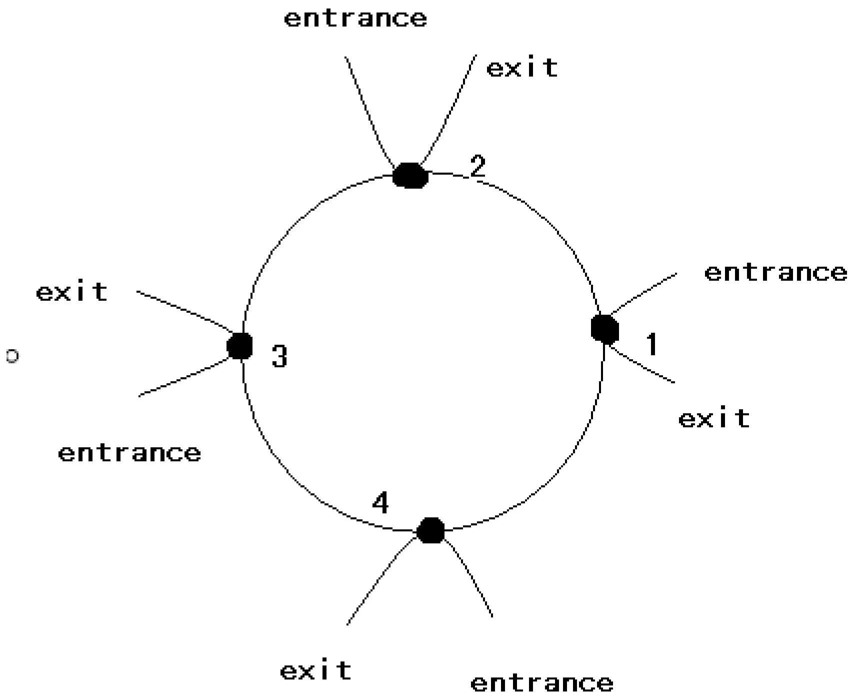


Figure 6.8

The black spots reprsent nodes in the network ,and they are named node 1, 2, 3 and so on. The network above can be called the Jackson Net , it obeys the following rules:

- Unlimited customers.
- Number of customers of node $i$ has a mean arrival rate of $a_i$ tracks/min in Poisson distribution. $a_i$ can be measured by engineers ,so we regarded as an known value.
- There is an service desk at node i,and service-time of each service-desk satisfying negative exponential distribution with parameter $\mu_i$.According to probability theory the mean value of this distribution is $1/\mu_i$,which equals mean value of waiting time of each vehicle at the
- the customers at node i transfer to node j with the probability $p_{ij}$ and the probability of leaving the system is $q_i = 1 - \sum_{i=1}^{m} p_{ij}$ .where ( $p_{ij}$ ) can be obtained from the Bay Road probability matrix M.

Then the arrival rate of node j

$$\lambda_i = a_j + \sum_{i=1}^{m} \lambda_i p_{ij}$$

Then according to the most powerful relationship in queueing theory ,i.e. Little's formula,

$$W = \frac{L}{\lambda}$$

Where $W$ is average length of stay,
L is system size，
$\lambda$ is average arrival rate.

We also developed the program that can calculate the average waiting time, system size,and average length of stay in the Appendix A.

## 7 Results

Applying the models established above,we bring forward four measures to deal with the circle traffic.

- test 1 refers to the unsignalized pattern.

- Measure 2 refers to the measure that the vehicles in the traffic circle have the priority. when the vehicles in the outside of the circle wanted to get in,he must see whether there are other vehicles in the circle, who will reach the conflict area while himself reach that area .Then he should decelerate and stop in front of the red stopline which showed in the figure below,and let the vehicle in the circle go first and then it is his turn.

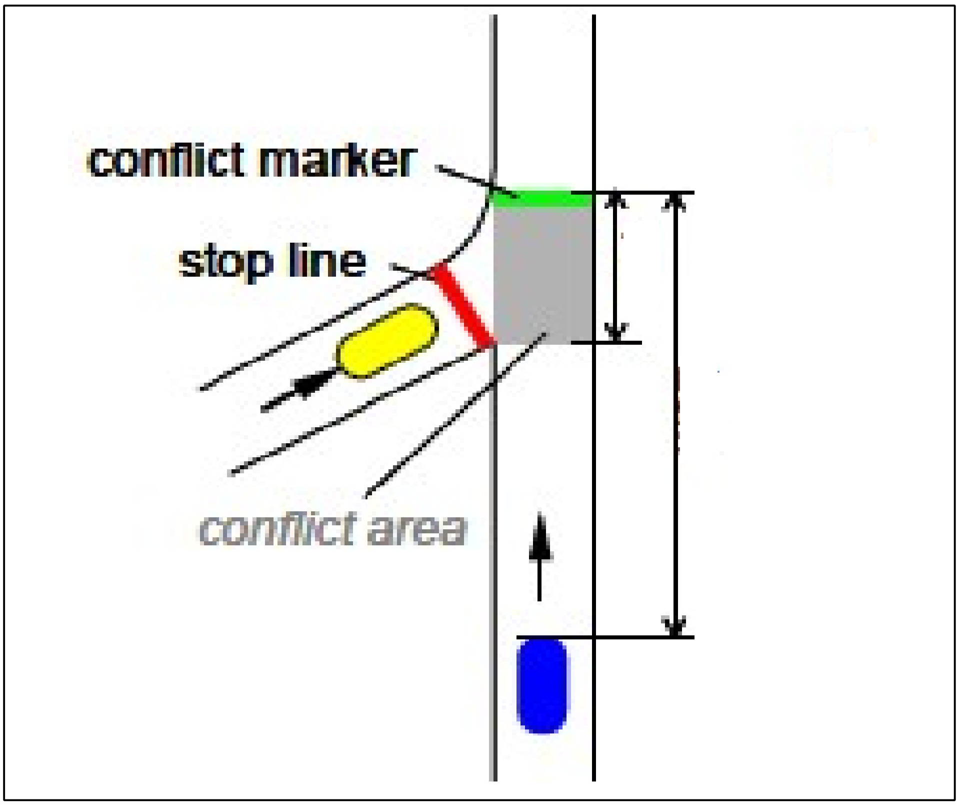


Figure 7.1: The priority rules(VISSIM 5.10 user manual)

- Measure 3 refers to the measure that the control signal is monophasic,and the signal light is set at every entrance to control the traffic toward inside. The cycle and the time of green time are determined by applying the Traffic Flow Model.

- Measure 4 refers to the measure that the control signal is biphase. The red phase and green phase are ascertain by the "green channel" model. The cycle is determined by the webster formula

These four different measures were simulated by traffic simulation software--VISSIM 5.10. And after calculating, average delayed time was used to evaluate four different measures.The simulated model using software VISSIM 5.10 is shown in figure 7.2.

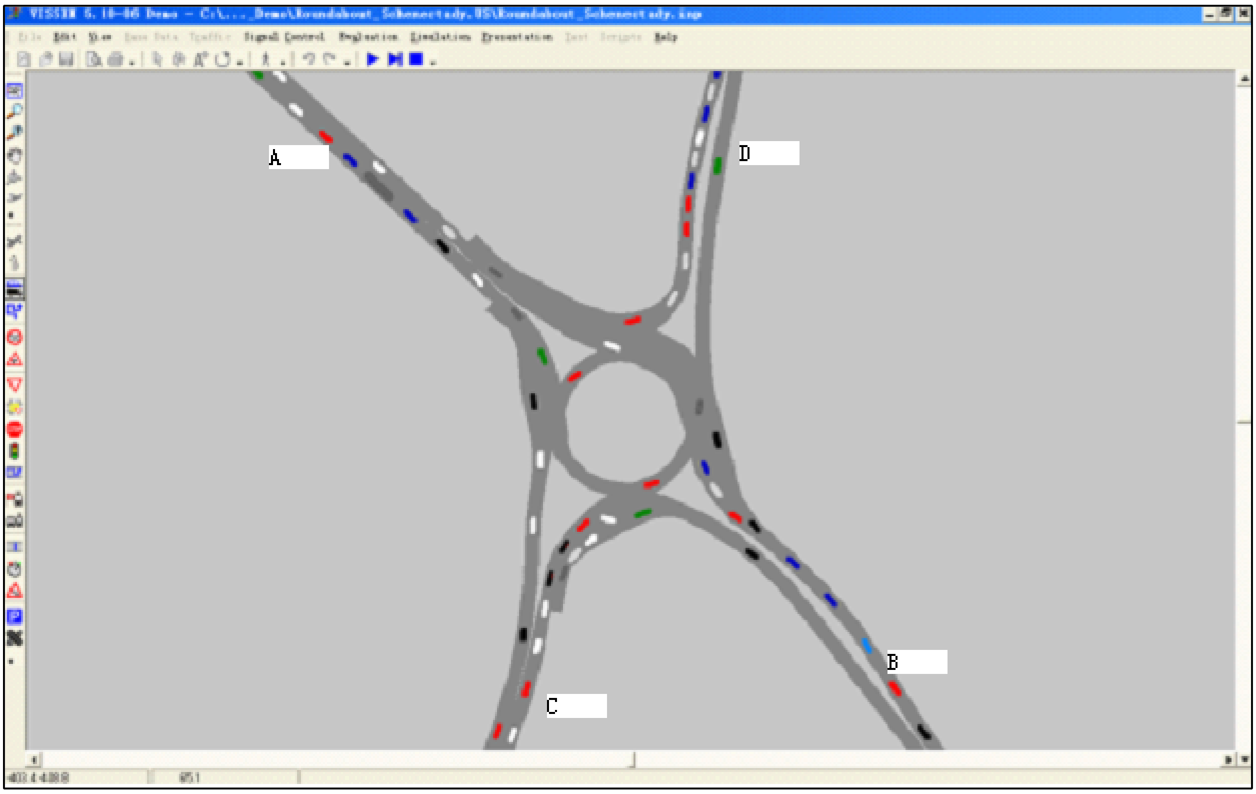


Figure 7.2

We assume the software can simulate our model well. Then the simulation can be done as below.

1 Point A,B,C,D are fixed and the average delayed time from A to B,C,D is calculated using the software.

2 We calculated the capacity of the circle approximately, applied the model established in the paper. The capacity is about 3000 Pcu/h in the unsignalized traffic circle,and same traffic flow was set in the four directions,which is 750 Pcu/h in each direction.

3 In Measure 3 and 4, the Traffic Flow Model is used to determine the cycle of

traffic
light and the ratio of the green phase in the cycle.

The delayed time is showed in the chart below.(Time's unit is second)

| | A→B | A→C | A→D | Ave.time |
|---|---|---|---|---|
| Mesure 1 | 217.6 | 131.8 | 75.7 | 142.68 |
| Mesure 1 | 179.1 | 150.2 | 101.7 | |
| Mesure 2 | 144.8 | 145.8 | 127.3 | 149.5 |
| Mesure 2 | 160.5 | 170.7 | 158.2 | |
| Mesure 3 | 114.2 | 81.2 | 71.4 | 92.083 |
| Mesure 3 | 132.1 | 105.3 | 99.5 | |
| Mesure 4 | 86.6 | 89.8 | 88.5 | 87.967 |
| Mesure 4 | 89.7 | 91.7 | 84.7 | |

Chart 7.1: The delayed time

Then we illustrated the average travel time of these measures. And the effect of different measures is reflected in figure 7.3.

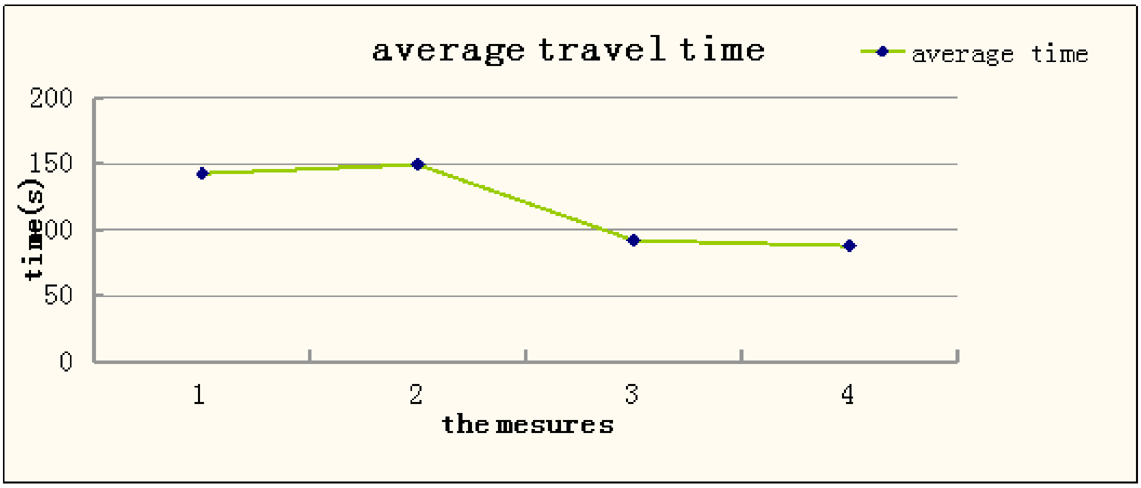


Figure 7.3

Then the traffic flow was set at a level of 2500 Puc/h in each direction.

| | A→B | A→C | A→D | Ave.time |
|---|---|---|---|---|
| Mesure 1 | 119.6 | 97.2 | 78.2 | 98.32 |
| Mesure 1 | 101.6 | 78.2 | 79.6 | |
| Mesure 2 | 146.2 | 146.2 | 165 | 144.9 |
| Mesure 2 | 153.4 | 136 | 122.6 | |

| | | | | |
|---|---|---|---|---|
| Mesure 3 | 166.2 | 133.4 | 138.8 | 143.16 |
| Mesure 3 | 156.4 | 129.2 | 135 | |
| Mesure 4 | 147.2 | 141.8 | 124.8 | 137.7 |
| Mesure 4 | 155.2 | 129.4 | 127.8 | |

Chart 7.2: The delayed time

The figure illustrated is in the bellow.

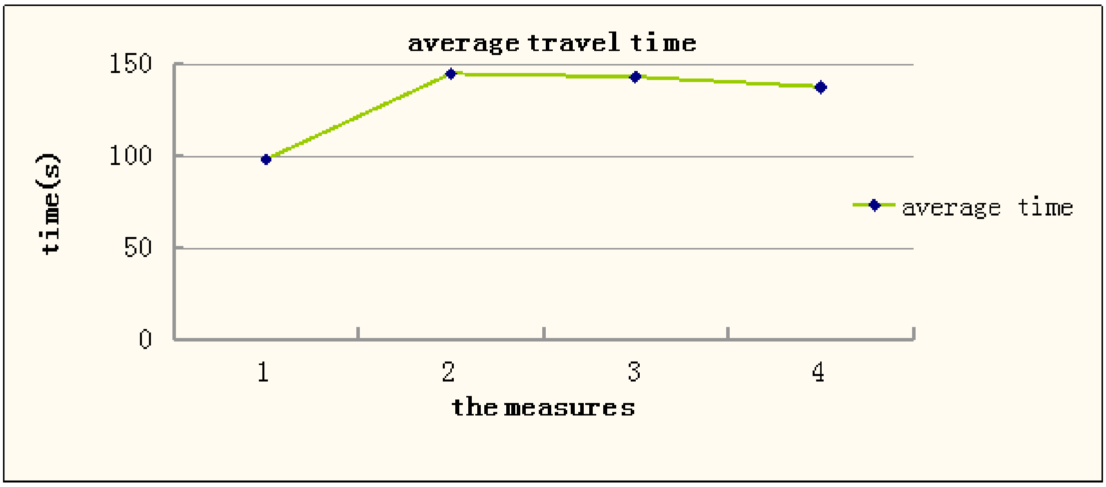


Figure 7.4

Comparing two figures, we can see that the delayed time of unsignalized circle is less than the time delayed in signalized circle when the traffic flow is not heavy, but the delayed time is more is increasing as the traffic flow becoming heavier.
In each figure,we can see the biphase method has an advantage over other signalized measures.

According to the analysis above, we can make a conclusion that the signal lights should be set to improve traffic circle's efficiency and alleviate the traffic pressure when the traffic flow has reached or exceed the capacity of the circle.

So a best control of traffic flow is a method that vary from time to time according to the traffic flow.we can advance a suitable measures,After surveying the distribution of traffic flow in a whole day .That is when the traffic flow is heavy ,the signalized measures is applied ,and when the traffic flow is light ,the unsignalized measures is applied.

# 8 Discussion and Conclusion

## 8.1 Strengths and Weaknesses

Our models have these strengths:

- Accounts for all major factors involved in traffic circle.
- Simulating all the four measures and comparing the efficiency of these measures comprehensively.
- The methods brought forward is executable and can largely improve the traffic situation.

Our models have these weaknesses:

- Parameters have to be derived from physical occurrences.
- Ignorance of many trivial details may affect the decision-making in some way.

## 8.2 Future Work/Model Generalization

- Raising some simple method to calculate the parameters.

- More other optimal simulates under specific situation.

# 9 Technical Summary

After mathematically analyzing the aircraft boarding problem, our modeling group would like to present our conclusions, strategies, and recommendations to the airline industry.

We put forward some executable measures to deal with the traffic circle problems .Each measure has been detailedly described.

Of course a simple method is setting no signs , no signals lights and never cared about it.This method seems irresponsible but in fact the best method when the traffic is light.We call it Measure 1 in our paper.

Another measure is setting a priority rule with stop signs and yield signs to alleviate the pressure in the circle.It is not so suitable just judging from the traffic effect,but it can operate very well if the traffic is light,and is safer for drivers comparing to Measure 1.We call it Measure 2.You are required to set a yield sign on the in-coming feeder road and set stop lines at the right position. According to the priority,when the driver sees the stop sign,he should stop at the stop line.

When the traffic is heavy,you would have to turn to traffic lights.You should set a signal light at the entrance of every feeder road . To obtain the time of green light and red light,you should make a survey of every feeder road's traffic flow and the other parameters of the traffic circle. Then **Webster formula** will give you the cycle length.and another formula $t_g \geq \frac{\rho_m}{\rho_m - \rho_0}\tau$ . This measure can deal with heavy traffic.

When the phases of all the signal are the same(we call it measure 3), the process is very simple.So it is advised to be used in small traffic circles .

When the phases vary for different traffic lights ,we call it measure 4.This measure is often used in complicated projects and under heavy traffic flow,.You should collect the information of the traffic.Additionally,you should use the method mentioned in the "Green Channel"model to acquire the offset of green light and red light phase. If you have the condition to control the traffic lights change according the traffic flow,you can raise a better method for your project.After analyzing the probability of traffic flow in a whole day , use Measure 4 under heavy traffic flow,and Measure 1 under light traffic flow.

Please attention,when the traffic flow is too heavy,maybe all these measures will not bring the expected result for you. In this situation,you will have to take other measures like broaden the road or replace the traffic circle with better transportation facility.

# References

[1] M.Hossain.*Capacity estimation of traffic circles under mixed traffic conditions using micro-simulation technique*.Transportation Research,Part A:Policy and Practice,v33,n1,Jan,1999,p47-61.

[2] Jiang Qiyuan,Xie Jinxing. *Mathematical model(Third Edition)*. Bei Jing: Higher Education Press，2003.

## Appendix

```
% Matlab program of Jackson Net based on queueing theory
%
%    E.g. when we choose
%    P=[0 0.8 0 0 ;0 0 0.3 0;0 0 0 0.85 ;0.25 0 0 0];
%    a=[-1425/3600 -1425/3600    -1420/3600 -1485/3600];
%    c=[1 1 1 1];
%    u=[1 1 1 1];
%    then the output will be
%    w = 2488/219, rou =[1607/1711, 811/1194,1007/1066,2173/3357],
%    y = [1607/1711 ,811/1194 ,1007/1066,2173/3357]'
%    L =[5300/343,2397/1132,9814/575,2173/1184].

function [rou,y,L]=JacksonNet(a,c,u,P)
format long;
A=a-eye(4);
y=linesolution(A,b');
rou=y'./(s.*u);
L=y'./(u-y');
w=sum(L)/sum(y)
```