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Optimal control of traffic light signals using stochastic simulation

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Abstract. Traffic congestion is one of the serious problems facing modern cities, posing a huge challenge to people's travel and urban development. And it has been proved that traffic lights should be responsible for the congestion instead of too many cars on the road occasionally. So it is very important to find the optimal control of the traffic light signal. The purpose of this experiment is to explore ways to optimally control traffic light signals in order to reduce the average waiting time for people and vehicles at intersections. This paper used a stochastic simulation approach, based on an assumed Poisson process and Gamma distribution, to simulate the specific time for vehicles and pedestrians to arrive at the intersection over the course of an hour, and used this to calculate the average waiting time. We investigated the effect of the duration of red and green lights on the average waiting time and wrote the corresponding code for simulation and calculation through MATLAB. The experimental results show that shorter red light duration and moderate green light duration can achieve optimal results when there are more cars. On the contrary, shorter green light duration and moderate red light duration can achieve optimal results when there are more pedestrians. We reached this conclusion through experiments and evaluated the hypotheses in the experiments.

Keywords: Stochastic Simulation, Traffic Light Optimization, Exponential Distribution, MATLAB.

1. Introduction

Traffic congestion is one of the serious problems facing modern cities, which brings great challenges to people's travel and urban development. In the urban transportation system, traffic lights, as an important traffic signal control means, play a key role in guiding the flow of vehicles and ensuring traffic safety, and optimal traffic light control can make the transportation system more efficient, safe, and sustainable.

The impacts of traffic signal timing optimization on vehicular fuel consumption and emissions in an urban corridor were investigated by Jaeyoung Kwak et al. [1]. Junchen Jin et al. proposed a model-based optimization framework to integrate essential components for solving road traffic control problems in general [2]. Xinghua Hu et al. studied the impact of bus priority control on traffic carbon emissions under the strategies of speed guidance, green extension, and red truncation [3]. Traffic models, fuel consumption and emissions models, optimization methods, objective functions, operating conditions, and reported sustainability savings were studied by Alshayeb et al. [4]. Proposed by Eleni Christofa and Alexander Skabardonis, a real-time system minimizes person delays by prioritizing transit vehicles

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based on occupancy and reducing auto traffic impact [5]. Similarly, a real-time signal control system that optimizes signal settings based on the minimization of person delay on arterials was proposed by Eleni Christofa et al. [6].This paper aims to investigate the impact of different traffic signal control strategies on the average waiting times of vehicles and pedestrians during traffic congestion by utilizing exponential distribution for conducting random simulations to optimize traffic signal control. This research aims to identify the optimal traffic signal control strategy to balance the waiting times of vehicles and pedestrians during traffic congestion. The findings can enhance traffic efficiency, improve pedestrian convenience, and contribute to the optimization and enhancement of urban transportation systems, as seen in Figure 1.

2. Experimental Design

The aim of this experiment is to to find the best strategy for traffic light control at one-way intersections using stochastic simulation methods.

2.1. Hypothesis

1. The intersection has no divergence, and the traffic light does not have a yellow light.

2. If the light is red when the car arrives at the intersection, it will slow down evenly until it stops.

3. The minimum time for a person to cross the road is 5 seconds. When a person finds that the green light starts flashing (turns red after 5 seconds), he or she stops crossing the road and waits for the next green light.

4. Speed of the car, and so on (which will be introduced in the code).

Figure 1. Research Purpose.

2.2. Research Steps

Based on these assumptions, we conducted experiments using stochastic simulation to calculate the

average waiting time for red lights by simulating the arrival time and number of vehicles and pedestrians, as well as the duration of the red and green lights. We evaluate the average waiting time under different scenarios by controlling the duration of red and green lights and simulating the arrival of vehicles and pedestrians based on a random distribution of the arrival time interval.

• Set different numbers of cars and people arriving at the intersection within one hour according to different times of the day.

• Calculate the parameters of the Gamma distribution according to the set parameters and generate random numbers.

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• Calculate the average waiting time for cars and people based on the generated random numbers.

• Select the optimal traffic light control time in different time periods based on the average waiting time

In particular, taking into account the queuing of cars at red lights, we calculate the waiting time for cars this way: (see Figure 2).

3. Results

We set the number of cars and people arriving at the intersection in one hour to 1500 and 500, and then 100 and 1000, respectively, and the result is as follows (see Figure 3).

When there are more cars than pedestrians, we get the following result: the optimal red light duration and green light duration are 15 s and 37 s, respectively, and the minimum average waiting time is 5.4097 s. When there are more pedestrians than cars, we get the following result: the optimal red light duration and green light duration are 39 s and 15 s, respectively, and the minimum average waiting time is 3.5531 s.

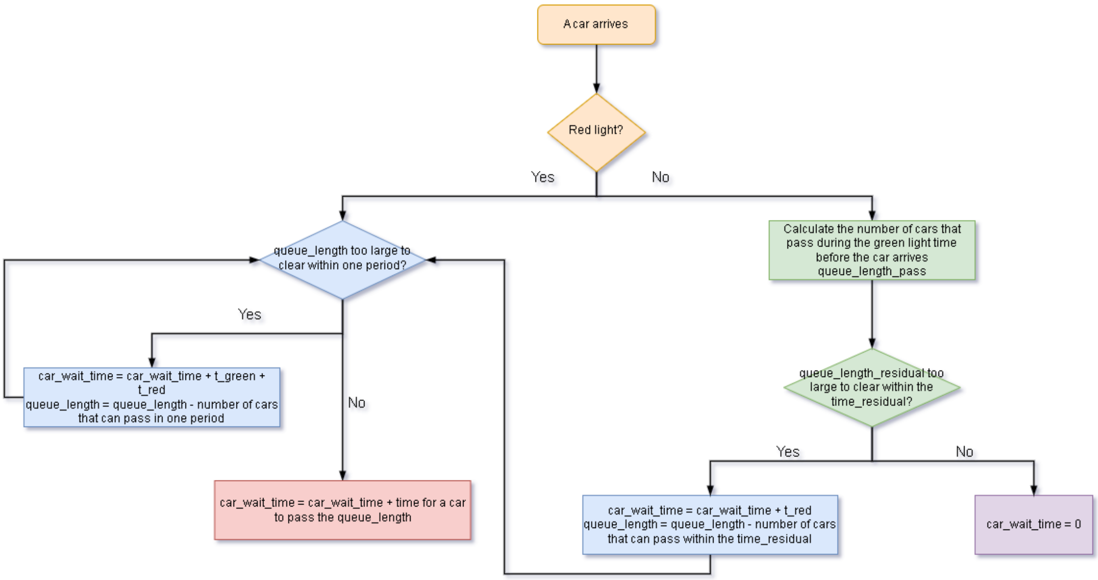

Figure 2. Steps to calculate the waiting time of cars.

When there are more cars than pedestrians, our intuition is that the longer the green light and the shorter the red light, the better. Practical constraints result in the optimal green light duration not being the longest. Instead, there exists a different optimal time that minimizes the weighted average waiting time. The same is true when there are more people than cars.

4. Discussion

In that experiment, this paper's proposed algorithm has several advantages:

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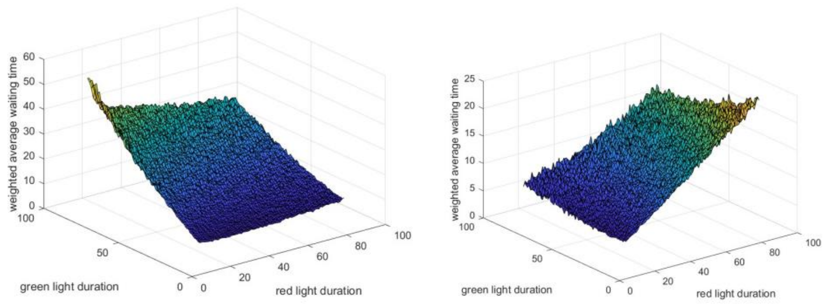

(a)More cars than pedestrians (b) More pedestrians than cars

Figure 3. Two scenarios.

1. Applicability: The algorithm has wide applicability in simulating traffic flow and optimizing traffic light control. It is able to take into account the random arrival behavior of vehicles and pedestrians, and incorporates the Poisson process and Gamma distribution to simulate and predict changes in traffic flow. This allows the algorithm to adapt to different scenarios and traffic conditions, thus better optimizing the traffic light control strategy.

2. Accuracy: By modeling traffic flow using Poisson processes and Gamma distributions, the algorithm is able to provide more accurate results and predictions. These statistical models capture the randomness and volatility of traffic flow., thus better reflecting the actual situation. By performing stochastic simulations based on these models, the algorithm is able to generate more realistic and reliable traffic data and optimize the performance of the traffic system by evaluating different traffic light control strategies.

3. Adjustability: the parameters and strategies of the algorithm have a certain degree of adjustability. You can adjust the arrival rate parameter of the Poisson process and the shape parameter and scale parameter of the Gamma distribution according to the specific traffic environment and demand. By adjusting these parameters, you can optimize the traffic light control strategy according to the actual situation to make it more in line with the actual demand and achieve better traffic results.

5. Conclusion

Many assumptions are used in experiments, and these simplify the complexity of the problem to some extent, allowing for more feasible and controllable experiments. However, we should also recognize that these assumptions may differ from the actual situation, limiting the accuracy and realism of the experiment. In practical applications, we need to combine more actual data and situational information to verify and revise the assumptions in order to improve the reliability and applicability of the experimental results.

Therefore, this experiment is a simulation of traffic light control and its traffic situation at an intersection under ideal conditions, which can be used to get a preliminary idea of vehicles and pedestrians passing through the intersection.

Therefore, it is necessary to consider more practical factors in the future to obtain more realistic results. For example, consider the driver’s response time to start the car after seeing the red light becomes green; consider a complex solution, that is, when the driver finds it, the signal becomes green during the deceleration process, and then accelerates; consider the intersection of the two roads. crossroads.

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