Research on Unregulated Emissions from Motor Vehicles at Intersection Based on the Optimized Traffic Signal Timing

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Abstract. This paper centers on optimizing the signal timing scheme to reduce motor vehicle unregulated emissions from motor vehicles at the intersection by the integration method of VISSIM and MOVES. Taking the intersection of Hong Kong Middle Road and Fuzhou South Road in Qingdao as the research object. In VISSIM, according to the traffic flow, the signal timing scheme is optimized. The localized MOVES emission model calculates emissions of formaldehyde, ammonia and benzene. Compared with emissions of regulated pollutants before and after the optimization for the signal timing scheme, the result shows the optimized signal timing improves the passing capacity of the road intersection, and emissions of formaldehyde, NH3 and benzene reduces by 22%, 7% and 14% respectively. The result indicates that the optimized signal timing can effectively reduce motor vehicle unregulated emissions at the road intersection, which provides an effective way to protect the environment.

Keywords. Unregulated emissions; road intersection; optimized traffic signal timing; traffic flow; MOVES.

1. Introduction

In Chinese cities, with the rapid growth of both the economy and the motor vehicle fleet [1, 2]. Vehicle emissions have become a major source of air pollution. By the end of 2017, there were approximately 208 million vehicles, which accounted for 70% of the total motor vehicle in China [3]. Although vehicle emission control standards has been more tightened, air quality was the most attractive in public. Vehicle emissions control has become an important part of improving China’s air quality [4, 5].

Traffic congestion has a serious impact on travel and delay time. This can be addressed to some extent by taking appropriate control measures that contribute to the optimal use of existing infrastructure. When carefully designed, traffic signals can be an effective tool to reduce traffic congestion. Otherwise, delays and journey times will not be reduced, and serious congestion will be resulted [6]. A few researchers brought forward some optimization algorithms for traffic signal timing scheme such as the split-cycle offset optimization technique (SCOOT), Sydney coordinated adaptive traffic system (SCATS), synergized transport resources ensuring an advance management systems [7-9], and regional hierarchical optimized distributed effective system (RHODS). This kind of system can control the traffic signal adaptively and use predictive and intelligent optimization algorithm to configure the state of the traffic signal in real time according to the traffic flow. These optimization methods improve traffic capacity of the intersection by reducing the delay and travel time.

Road traffic state has a serious effect on air pollution. Emissions from vehicles in idle and start mechanism is high that in high speed [10]. So the optimization for traffic signals timing scheme may
affect vehicle emissions at the intersection by improving traffic capacity of the intersection. A few researchers do some researches about the problem [11]. For example, Hatem Abou-Senn and Essam Radwan adopt the integration method of VISSIM (traffic simulation software) and MOVES (emission model software) to investigate the effect of major key parameters, such as speed, acceleration and deceleration on CO₂ emissions [12]. Liu Huan and Matthew Barth researched the overall effects that a vehicle’s short-term operating history had on its subsequent emissions. They found that high Vehicle Specific Power (VSP)-based vehicle emission models influenced the emissions of carbon monoxide (CO) while hydrocarbon variation ranges from 40% to 60% depending on the driving operation[13].

Some studies have verified that regulated pollutants emissions from motor vehicles, such as CO, CO₂, HC, NOₓ and PM₂₅ [14-16]. However, the influence that the optimized traffic signal scheme at the intersection has on unregulated pollutants emissions from motor vehicles is never considered. Unregulated pollutants do great harm to human health. They are not only irritant and allergenic, but also have potential genetic toxicity and carcinogenic activities. The paper focuses on investigate how optimized traffic signal timing scheme affects unregulated pollutants emissions from motor vehicles. We choose formaldehyde, ammonia, benzene emissions from motor vehicles at the intersection as the objective of our research. The traffic signal timing scheme at the Qingdao Middle Road and Fuzhou South Road in Qingdao is optimized by equivalent traffic flow method. Unregulated emissions from motor vehicles at the intersection are calculated by the integration of VISSIM and MOVES. The comparison of unregulated emissions before and after the optimization reveals influence that traffic signal timing scheme has on unregulated emissions from motor vehicles at the intersection.

2. Materials and Methods

2.1. Traffic Flow Experiment
Traffic congestion at the intersection of Hongkong Middle Road and Fuzhou South Road is one of the most severe areas in Qingdao. In the paper, we select the intersection as the object of the study. The intersection of Hongkong Middle Road and Fuzhou South Road in Qingdao is shown in figure 1.

![Figure 1. The intersection of Hongkong Middle Road and Fuzhou South Road in Qingdao.](image)

The traffic flow at the intersection of Hongkong Middle Road and Fuzhou South Road is surveyed on the morning peak (7:00-8:00) of all working days in November, 2015. The average traffic flow at the intersection is shown in table 1.

| Time         | East import | West import | South import | North import |
|--------------|-------------|-------------|--------------|-------------|
| Morning peak | 756         | 652         | 389          | 1039        |

The velocity of motor vehicles at the intersection is recorded by GPS vehicle travelling data recorder. GPS vehicle travelling data recorder is shown in figure 2.
According to the data recorded by the GPS vehicle traveling data recorder, velocity distribution of motor vehicles at morning peak is shown in figure 3. The average velocity of motor vehicles at morning peak is 13.9 km/h.

![Figure 2. GPS vehicle travelling data recorder.](image)

2.2. Operating Mode Distribution of Motor Vehicle

Operating mode distribution of motor vehicles at the intersection is obtained by combination of velocity of motor vehicles and the specific power (VSP). VSP of motor vehicle is the power to be output to shift each ton of the motor vehicle and the unit is kw/t or w/kg. Calculation of VSP is presented in equation (1) [17].

\[
VSP = V \times (0.132 + 1.1a) + 0.302 \times 10^{-3}
\]

where \( V \) is the instantaneous velocity of vehicle, m/s; and \( a \) is the instantaneous acceleration of vehicle, m/s\(^2\).

When the velocity of motor vehicle is 0, VSP must be 0; VSP is a vector, when vehicle is decelerating, the direction of its driving force and the direction of its velocity are opposite, so VSP of motor vehicle is negative at this time; when vehicle is accelerating, its force direction and its driving direction is same, VSP is positive at the moment.

VSP is divided into different bins by the method of clustering. The instantaneous emission rate at every VSP bin is defined as the emission rate of motor vehicles at the interval. Speed of motor vehicles is divided into different intervals. Operating mode distribution of motor vehicles is divided into 23 intervals by the combination of VSP and speed of motor vehicles. The proportion of the operating mode of motor vehicles at different link is equal to the proportion of the number of motor vehicles at different operating mode accounting for the total number of motors vehicles at the link. The
operating mode distribution of motor vehicles at different link is shown in table 2.

| Mode | VSP       | Velocity | Link 1 | Link 2 | Link 3 | Link 4 |
|------|-----------|----------|--------|--------|--------|--------|
| 0    | Braking   | 0        | 0.1    | 0.10373| 0.11041| 0.0885 |
| 1    | Idle      | [0, 1.5] | 0.03428| 0.03319| 0.01875| 0.0257 |
| 2    | [-inf, 0] | [1.5, 40]| 0.31742| 0.03319| 0.01875| 0.0257 |
| 3    | [0, 3]    | [1.5, 40]| 0.31714| 0.31742| 0.37291| 0.4371 |
| 4    | [3, 6]    | [1.5, 40]| 0.15714| 0.06224| 0.03333| 0.0228 |
| 5    | [6, 9]    | [1.5, 40]| 0.02285| 0.04979| 0.02291| 0.0142 |
| 6    | [9, 12]   | [1.5, 40]| 0.03714| 0.03527| 0.01875| 0.0085 |
| 7    | [-inf, 12]| [1.5, 40]| 0.28285| 0.27385| 0.3      | 0.3828 |
| 8    | [-inf, 0] | [40, 80] | 0.00285| 0        | 0.0125  | 0      |
| 9    | [0, 3]    | [40, 80] | 0        | 0        | 0        | 0      |
| 10   | [3, 6]    | [40, 80] | 0        | 0        | 0        | 0      |
| 11   | [6, 9]    | [40, 80] | 0        | 0        | 0.00208 | 0      |
| 12   | [9, 12]   | [40, 80] | 0        | 0        | 0.00208 | 0      |
| 13   | [12, 18]  | [40, 80] | 0        | 0        | 0        | 0      |
| 14   | [18, 24]  | [40, 80] | 0        | 0        | 0        | 0      |
| 15   | [24, 30]  | [40, 80] | 0        | 0        | 0        | 0      |
| 16   | [-inf, 30]| [40, 80] | 0        | 0        | 0.01458 | 0      |
| 17   | [-inf, 6] | [80, 120]| 0        | 0        | 0        | 0      |
| 18   | [6, 12]   | [80, 120]| 0        | 0        | 0        | 0      |
| 19   | [12, 18]  | [80, 120]| 0        | 0        | 0        | 0      |
| 20   | [18, 24]  | [80, 120]| 0        | 0        | 0        | 0      |
| 21   | [24, 30]  | [80, 120]| 0        | 0        | 0        | 0      |
| 22   | [30, inf] | [80, 120]| 0        | 0        | 0        | 0      |

*Note: Link1 represents the east import; link2- west import; link3- south import; link4- north import.

2.3. *The Signal Timing Scheme at the Intersection*

Information including the number of lanes, lane width, the number of turning left straight roads, the number of turning right straight roads and others is put into VISSIM to create the traffic simulation model of the intersection of Hong Kong Middle Road and Fuzhou South Road [18]. The simulation model of the intersection in VISSIM is shown in figure 4.

The signal timing scheme including the cycle of the traffic signal lights T0 and the time length of green signal light and red signal light at each import is edited and put into the signal control block of VISSIM. The signal timing scheme at the intersection is seen in table 3.

As the amber light has been canceled in VISSIM, the traffic signal group includes green light, red light and flash. The staring time of the green light turning left is two seconds later than that of the green light straight at four links by investigation. The signal timing scheme in VISSIM is seen in figure 5.

3. Results and Discussion

3.1. *The Optimized Signal Timing Scheme at the Intersection*

The optimization for signal timing scheme at the intersection adopts the calculation method of equivalent traffic flow. The equation to calculate the equivalent traffic flow is presented in equation (2).
Table 3. Intersection signal timing scheme.

| No. | Program              | Link 1 /s | Link2/s | Link 3 /s | Link 4 /s |
|-----|----------------------|-----------|---------|-----------|-----------|
| 1   | $T_0$ cycle          | 174       | 174     | 174       | 174       |
| 2   | Green light length   | 46        | 46      | 50        | 28        |
| 3   | Red light length     | 128       | 128     | 124       | 146       |

Figure 4. VISSIM simulation model of intersection.

Figure 5. Intersection signal timing scheme.

$$V_e = (V + 0.5H + 0.6L)/n \quad (2)$$

$V_e$ is the equivalent traffic flow; $V$ is the actual import traffic flow; $H$ is the number of around turning vehicles; $L$ is the number of left turning vehicles; $n$ is the number of lanes at the intersection.

The equation to calculate the traffic signal cycle length is presented in equation (3).

$$T = 13330P/(1333 - V_e) \quad (3)$$

$T$ is the traffic signal cycle length; $P$ is the number of phases.

The traffic signal cycle is 92.28 seconds through calculation. If the cycle is too small, that could cause safety problem. And if the cycle exceeds a certain limit, the growth of its traffic capacity tends to stagnate, and the delay time of vehicles at the intersection grows faster. The optimized signal timing cycle is set as 1.5 times and 2.0 times of the cycle, namely $T_1$=140 seconds and $T_2$=186 seconds. According to the proportion of the equivalent traffic flow, the green light time is assigned to each import. The length of the green light at $T_0$ cycle and $T_1$ cycles are put into VISSIM to calculate the delay time of vehicles at the intersection. The comparison of the delay time at $T_0$ cycle, $T_1$ cycle is seen as figure 6.
Figure 6. The delay time at T0 cycle, T1 cycle and T2 cycle.

According to the comparison of the delay time at T0 cycle, T1 cycle and T2 cycle, the delay time at T1 cycle is shorter than the delay time at T2 cycle. T1 cycle is selected as the optimized signal timing scheme.

3.2. Effects of Optimized Traffic Signal Timing on Unregulated Emissions
The operating mode distribution of motor vehicles, the local vehicle information, the fuel information and the climate information are put into MOVES to create the localized MOVES emission model [19]. The localized MOVES emission model calculates emissions of formaldehyde, ammonia and benzene at the intersection in morning peak at the T1 cycle and the T0 cycle. Emissions of formaldehyde, NH3 and benzene at the T0 cycle and T1 cycle is shown in figure 7.

Figure 7. Emissions of formaldehyde, NH3 and benzene.

The comparison between emissions of the unregulated pollutants at the T0 cycle and the T1 cycle shows: emissions of formaldehyde reduce by 22%, ammonia by 7% and benzene by 14%. After the optimization, the delay time of the four links reduces 39%, 13%, 4% and 20% respectively. The total traffic flow per unit time is increased by 21% at the intersection. The intersection passing capacity is improved, and the idle running time of motor vehicles at the intersection is reduced. Because formaldehyde is produced by incomplete combustion of hydrocarbon fuel and the idle running time of motor vehicles at the intersection reduces, the reduction of it is most obvious after optimization; As our traffic rule regulate that the content of benzene in fuel is relatively low, the optimized signal timing scheme makes emissions of benzene reduce, but lower than the reduction of formaldehyde;
emissions of ammonia is mainly exhaust gas catalytic device to eliminate nitrogen dioxide in the process of secondary product. Compared with emissions of ammonia between the idle running operation and the normal running operation, emissions of ammonia change a few. So emissions of ammonia reduce very little.

4. Conclusion
In this paper, the simulation of the intersection of Hongkong Middle Road and Fuzhou South Road is created in VISSIM. The comparison of the delay time between $T_0$ cycle and $T_1$ cycle shows that the latter improves the road intersection passing capacity. The localized MOVES emission model calculates emissions of formaldehyde, ammonia and benzene at the two kind of signal timing. The comparison between emissions of the signal timing and the optimized signal timing shows: emissions of formaldehyde reduce by 22%, ammonia by 7% and benzene by 14%. Emissions of three unregulated pollutants significantly reduce.

This indicates that the optimized signal timing scheme reduces motor vehicles unregulated emissions by increasing passing capacity of the intersection, which reduces the idling time of motor vehicles at road intersections. The optimization for the signal timing scheme provides a new approach to reduce unregulated emissions.

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