intersection. The Michigan Department of Transportation [1] has provided median openings for U-turns on highways with wide-medians and prohibited all left-turns at major signalized intersections for many decades. The result indicated that capacity of the intersection was increased by 15 to 18 percent compared with dual left-turn lanes, and additional delay due to the increased travel distance of the indirect left turn was less than the conventional left-turn treatment. Hummer and Reid [2] studied a high-volume intersection, using CORSIM to simulate traffic performance and using SYNCHRO to develop optimized signal timings. Four time periods were analyzed, including morning, noon, midday (2:00 PM to 3:00 PM), and evening peak periods. They found that the median U-turn was superior to the two-way left-turn lane in capacity and corridor speed. Xiaokuan Yang [3] used CORSIM to compare the direct left turn with U-turn in terms of delay and travel time. Yang concluded that the U-turn was superior to the direct left turn in the high volume situations. Kentucky Transportation Center [4] studied New Circle Road using CORSIM, concluded that U-turn left turns enhance the operation of the corridor due to the more efficient processing of left turn vehicles at the downstream intersection. Also, they recommended that U-turns be considered for corridors with peak volumes greater than 1,500 vph or for cases where the expected total turn volume is greater than 20 percent of the total approach volume. Other researches [5,6,7] also proved superiority of U-turn left turn treatment for signalized intersections various perspectives.

Traffic mix at ramp terminal intersections is more complex than normal signalized intersections. Ramp terminal locations include ramp traffic merging with traffic from collector roads, within a short distance making left-turns, proceeding through and turning right at the main collector/arterial intersection.

This paper will apply basic access management principles to improve a complex intersection connecting a ramp terminal of the 2nd Ring Expressway and the Wanbao Arterial in Hunan Changsha city. This paper will evaluate the operation of two alternatives: direct left turn and indirect left turn (median U-turn) using VISSIM.

The following sections will discuss existing conditions of the intersection, improvement alternatives analyzed, simulation results using VISSIM for the two alternatives for the AM & PM peak periods and conclusions of the analysis.

## 2 Existing Conditions

### 2.1 Geometric condition of intersection

The study intersection is located in the northeast district of Changsha in Hunan province of China, intersecting roads include collector road of 2nd Ring urban expressway and Wanbao arterial road (Figure 2). Here, the 2nd Ring urban expressway and collector road is north-south bound, and Wanbao aterial road is east-west bound. The expressway is an elevated road lying over its parallel collector road, and connects to the collector road by on and off ramps.

Both north and south approaches have 5 lanes, 2 exclusive left-turn lanes, 2 straight lanes and one right-turn lane. Both east/west approaches have 3 lanes, one for left-turn, one for straight and one for right-turn movements dividedly. Two lane ramps are located 100 meters from stop line upstream of main intersection.

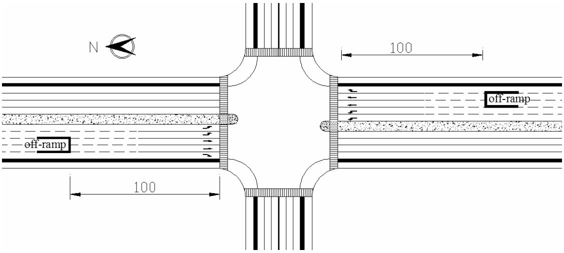


**Figure 2. Geometric condition of the intersection**

### 2.2 Traffic demand

This major expressway/arterial intersection carries heavy traffic. During the AM peak hour from 7:20 to 8:20, the total intersection volume was up to 6428 pcu/h, in which ramp in the north approach shared 557pcu/h and ramp in the south approach shared 689 pcu/h. During the PM peak hour from 17:55 to 18:55, the whole traffic volume was up to 6562 pcu/h, in which ramp in the north approach shared 573 pcu/h, and ramp in the south approach 742 pcu/h. Traffic volume data is included in Table 1.

The composition of traffic was: large vehicle 22.5%, car 39% and others 38.5%.

**Table 1. Traffic volume of the intersection (pcu/h)**

| Direction / Approach | | AM peak hour (7:20 - 8:20) | | | PM peak hour (17:55 - 18:55) | | |
|---|---|---|---|---|---|---|---|
| | | Left-turn | Straight | Right-turn | Left-turn | Straight | Right-turn |
| East | | 238 | 580 | 253 | 333 | 382 | 127 |
| West | | 448 | 608 | 341 | 298 | 356 | 549 |
| North | Collector | 521 | 576 | 306 | 70 | 969 | 269 |
| | Ramp | 207 | 229 | 121 | 30 | 425 | 118 |
| South | Collector | 462 | 552 | 297 | 326 | 1318 | 250 |
| | Ramp | 243 | 290 | 156 | 128 | 516 | 98 |

## 3 Evaluation of Direct Left-turn vs. Indirect Left-turn

### 3.1 Direct left-turn

Advantages of the direct left turn alternative include[6]: (1) For low traffic volumes, delay and travel time may be less than the indirect left-turn alternative; and (2) Vehicles making direct left turns travel less distance than the indirect left-turn. Disadvantages of the direct left turn alternative include: (1) Traffic delay and travel time may greatly increase under high traffic volume conditions; (2) Four-phase timing plans will result in more signal time loss; (3) Left-turn vehicles from the ramp and straight vehicles from the collector road must weave to enter the their destination lane; (4) Increased volumes and queues may extend to expressway mainline.

Based on above, the total travel time can be defined by the following equation:

$$T_L = t_{L1} + t_{L2} \tag{1}$$

Where: $T_L$ – average total travel time of direct left-turn alternative,
$t_{L1}$ – average delay of vehicles due to signal,
$t_{L2}$ – average delay of vehicles due to interweave.

**3.2 Indirect Left Turn Alternative**

Advantages of the indirect left turn include: (1) Travel time is shorter, delay is reduced and capacity is increased. For distances of less than 0.5 mile the indirect left turn will be more effective because the travel time will be comparable with the travel time of the direct left turn. (2) High left turn volumes requiring left turn phases with long green times may reduce intersection capacity and increase the delay of the though movements, U-turns will improve the traffic flow conditions by reducing the vehicle travel time. (3) Interweave between left-turn movements from ramp and straight movements from collector road can be eliminated due to left turn being relocated to the U-turn beyond the main intersection.

Disadvantages of the indirect left turn include: (1) Higher delay compared to the direct left turn alternative if major road traffic volume is low; (2) Longer travel distance may increase fuel consumption when compared to a direct left turn.

Based on above, the total travel time can be defined by the following equation:

$$T_S = t_{S1} + t_{S2} \tag{2}$$

Where: $T_S$ – average total travel time of indirect left turn alternative,
$t_{S1}$ – average delay of vehicles due to the signal,
$t_{S2}$ – average delay of vehicles at the U-turn median opening.

**4 Simulation Models**

VISSIM 4.1 was used to simulate the traffic operation of the two alternatives for AM peak and PM peak traffic volume scenarios.

**4.1 Simulation model of direct left-turn**

To model real traffic operations, the following assumptions were made: (1) The five approach lanes for north/south are numbered in sequence increasing from curb to median, the right turn lane is lane 1, as shown in Figure 1. (2) At the north/south approach, left-turn movements from the collector road will enter the approach lane 5 without disruption; straight movements from the ramp can enter the approach lane 2 without disruption; left-turns from ramp and straight from collector road must interweave using lanes 3 and 4; the area between ramp terminal and stop-line of intersection is a classic A-type weaving section. (3) Overflow was not evaluated and will not extend to upstream intersections. (4) The four-phase timing plan provides protected left-turn phases for both N/S and E/W.

**4.2 Simulation model of indirect left-turn**

In the indirect left-turn alternative, the following assumptions were made: (1) The three-phase signal provides a protected phase for east/west left turns. (2) Left-turn movements of north/south approach are indirect, and left-turns of east/west approach pass through the intersection directly. (3) The indirect left turn (median U-turn) is designed on the parallel collector of the 2$^{nd}$ Ring expressway. Hummer and Reid [2] pointed out that the optimum distance from the opening of U-turn to intersection is about 180m. The distance for this analysis was designed to be 250m. The median U-turn model is illustrated in Figure 3.

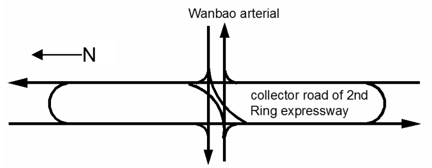


**Figure 3. Scenario of indirect left turn (median U-turn)**

## 5 Results and Discussion

The operational effects of the two alternatives were compared using travel time and delay. Tables 2-5 shows the simulation results of the two alternatives for AM and PM peak. Alternative 1 analyzed direct left-turns with a four-phase signal, and Alternative 2 analyzed indirect left turns with a three-phase signal. Data was collected for left-turn and straight movements (Table 2). North/south approaches were separated: expressway collector road and expressway off-ramp.

**Table 2. Comparison of Travel Time (seconds)**

| Approach \ Direction | | AM peak hour (7:20 - 8:20) | | | | PM peak hour (17:55 - 18:55) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Left-turn | | Straight | | Left-turn | | Straight | |
| | | Alt. 1 | Alt. 2 | Alt. 1 | Alt. 2 | Alt. 1 | Alt. 2 | Alt. 1 | Alt. 2 |
| East | | 13.9 | 6.1 | 14.7 | 6.5 | 15.8 | 6.8 | 16.9 | 6.5 |
| West | | 11.9 | 5.8 | 15.2 | 6.8 | 14 | 10.2 | 23.5 | 8 |
| North | Collector | 87.8 | 141 | 91.5 | 30.7 | 97.5 | 129.1 | 83.7 | 21.2 |
| | Ramp | 95.6 | 150.8 | 45.5 | 25 | 83.5 | 112.3 | 54.5 | 18.1 |
| South | Collector | 68 | 130.2 | 95.5 | 34.8 | 79.8 | 111.1 | 89.4 | 29.9 |
| | Ramp | 75.6 | 139.1 | 89.1 | 28.5 | 79.8 | 89 | 61.4 | 18.8 |

Note: “collector” refers to the 2nd Ring expressway collector road, “ramp” refers to off-ramp of expressway.

From Table 2, we can find that: (1) Compared to Alternative 1, travel time of straight movements at any approach was reduced by 45-75 percent during AM and PM peak hour. Travel time was less for Alternative 2 due to fewer signal phases. (2) Travel time of left-turns on east/west approaches was reduced by 27-57 percent. (3) Travel time of left-turn on north/south approaches increased by 11-91 percent. The increased travel time is caused mainly by the additional distance of required by the indirect left-turn.

**Table 3. Comparison of Delay (seconds/vehicle)**

| Approach \ Direction | | AM peak hour (7:20 - 8:20) | | | | PM peak hour (17:55 - 18:55) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Left-turn | | Straight | | Left-turn | | Straight | |
| | | Alt. 1 | Alt. 2 | Alt. 1 | Alt. 2 | Alt. 1 | Alt. 2 | Alt. 1 | Alt. 2 |
| East | | 23.3 | 9.1 | 26 | 8.1 | 11.1 | 6.3 | 11.4 | 5.9 |
| West | | 88.9 | 20 | 27 | 9.2 | 11.5 | 6.4 | 18.3 | 6.2 |
| North | Collector | 72.1 | 124.9 | 75.1 | 10.1 | 63.1 | 77.7 | 66.5 | 8.8 |
| | Ramp | 77 | 125.9 | 31.8 | 10.1 | 69.8 | 80.9 | 42 | 6.5 |
| South | Collector | 42.4 | 115.9 | 83.1 | 10.1 | 56.1 | 48.1 | 72.9 | 16.5 |
| | Ramp | 64 | 110.8 | 72.4 | 10.1 | 77.4 | 35.4 | 48.7 | 7.8 |

From Table 3, we can discover: (1) Compared to Alternative 1, delays of straight flow in Alternative 2 were reduced by 48-87 percent during AM and PM peak hour. Delay was less for Alternative 2 due to fewer signal phases. (2) Delays of left-turn in Alternative 2 were reduced by 43-77 percent compared to Alternative 1 for the east/west approaches. (3) During AM peak hour, delays of left-turns at the north/south approaches increased by 64-170 percent.

Overall, we find: (1) Straight movements were improved by the indirect left turn. One reason is the reduction in the number of signal phases, the other is that weaving movements between flow on the expressway collector road and flow from expressway off-ramp are reduced due to the indirect left turn. (2) Indirect left-turns caused additional travel distance to complete the left-turn, and may add travel time. However, when the overall effect is evaluated this additional time can be cancelled out by its efficiency. (3) Traffic conditions can affect the operational efficiency of the indirect left-turn. From the results of AM and PM peak hour, we can conclude that traffic volume and traffic composition are key factors.

## 6 Conclusions

This paper applied the method of access management to a complicated signalized intersection. Indirect left turns were used to replace the direct left-turn. Using VISSIM 4.1, the direct left-turn and indirect left-turn were compared using travel time and delay. The results indicated that indirect left-turns can improve the operation quality to some extent especially on the straight movements. Traffic volume and mix significantly affect the indirect left-turn efficiency.

## 7 Acknowledgements

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**Experimental Research on the Effects of Oxygen-Enriched Air on Combustion in a Small Spark-Ignition Engine**

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*Abstract* - An investigation on the effects of oxygen-enriched air on engine performance was proposed. This investigation focuses on combustion performance. As the oxygen concentration of the air for combustion increases, the heat of combustion for an engine of the same size would increase. The size (displacement) of an engine can be effectively reduced to achieve the same power. Oxygen- enriched air will affect the combustion process and the overall engine thermodynamics. For example, as oxygen concentration is increased, under the same operating conditions, combustion temperature and cylinder pressure will be increased. The purpose of this study was to quantify these results for a range of operating conditions.

Results include detailed thermodynamic output of pressures and other properties as related to the oxygen concentration of the air used for combustion. Results also include engine performance parameters such as power, torque, fuel consumption, and thermal efficiency. In one case, the combustion performance of the engine was recorded for an equivalent load with different oxygen concentrations of air. For air enriched with 24% oxygen, the cylinder pressure was increased by about 15%, the heat of combustion increased, and both the maximum pressure and the increased heat of combustion were achieved more quickly. Other results were recorded.

## I. Introduction

A car is driven by the power that is released in the form of heat energy after the combustion of fuel in the engine. However, this same process of combustion releases pollutants to the atmosphere. The rising costs of petroleum, combined with the desire to reduce the pollutant effects of combustion have led to a finding ways to increase the efficiency of this combustion process. Thus, the latest research by experts and institutions around the world is being driven towards ways to improve power, decrease fuel consumption and reduce pollution from the combustion engine.

In the combustion process of an engine, full heat energy can only be released when all of the fuel has burned. Supplying sufficient fuel to the combustion chamber is easy enough; it is difficult to provide sufficient oxygen to burn all of the fuel in the combustion process. Therefore, it can be said that the main factor in determining the power an engine can produce is the amount of air (oxygen) available for combustion in the chamber, not the amount of fuel. Thus, it is very important to research a way to apply a technique, with regards to engine combustion, to increase the oxygen content in the intake air that will satisfy the minimum requirement of the amount of oxygen necessary to achieve a complete combustion of fuel without changing the quantity or quality of engine exhaust, and will also improve the power and economy of the engine as well. Theoretical analysis shows that when air is introduced into the combustion chamber, and when the air contains the optimum ratio of oxygen, the heat of combustion is increased and the rate of heat release is improved. The efficiency of the engine is improved while the hazardous gases resulting from the combustion process are reduced compared with the combustion resulting from the use of common air of the same mass.

The power output of a gasoline engine is lower than that produced by a diesel engine. There are more hydrocarbons (*HC*) and carbon dioxide ($CO_2$) present in the exhaust produced in a gasoline engine, causing more pollution to the environment, especially since a catalytic converter does not function when an engine is first started and the hazardous gases in the exhaust can not be effectively degraded effectively.

With a focus on the operating characteristics of a gasoline engine, an experiment was performed on a single-cylinder carbureted gasoline engine, with oxygen-enriched air. The experimental results were analyzed and are discussed in this paper.

## II. Experimental System and Procedures

The engine used in the experiment is the Honda Model G200, a single-cylinder carburetor engine. The technical specifications of the engine are shown in Table 1. A schematic of the experimental test system is shown in Figure 1.

A pressure sensor was installed on the engine cylinder head and a combustion analyzer was used for combustion analysis. Meanwhile, additional data collection and analysis tools were applied to collect and analyze the parameters of oxygen concentration in the entering air, engine speed, engine power, exhaust temperature and fuel consumption. Finally, the performance of combustion of gasoline combined with oxygen-enriched air is analyzed.

During the experiment, an oxygen cylinder (oxygen bomb) was used to supply oxygen to the engine. The oxygen is introduced the combustion chamber of the engine directly through the intake manifold by taking advantage of the negative pressure produced when the engine intakes air. With an oxygen analyzer placed in the engine intake manifold, analysis is performed to measure the oxygen concentration of the air that has been introduced into the engine cylinder to support combustion. At the same time, the amount of oxygen flow is controlled by a flow control valve. The combustion process of the engine is then analyzed at oxygen concentrations of 21% and 24%, respectively.

The purpose of this experiment is primarily to monitor internal combustion, power and torque, as well as tail gas emission of the engine when oxygen concentrations are increased. The analysis and research provided in this paper is focused on the combustion process of the engine cylinder only.

## III. Results and Discussion

A DEWE-800 combustion analyzer was used to measure the output of the engine with combustion supported by air in different oxygen concentrations. Through mathematical analysis of the results, maximum combustion pressure and the maximum rate of change of pressure, and location of the crank angle at each occurrence are calculated. Additionally, the parameters of cyclic variations of combustion for different air conditions are analyzed. Heat release law for various intake air conditions is determined through thermodynamic analysis of the results. Further, analysis is performed on the influence of engine combustion characteristics by the oxygen concentration in the entering air. The combustion process of the engine is studied primarily through the following four parameters.

### *A. Analysis of Combustion Pressure*

Analysis is performed regarding the maximum combustion pressure, $P_{max}$, and the position of the crank angle at $P_{max}$. A corresponding relationship exists between the maximum combustion pressure and an engine's thermal efficiency and power. The higher the maximum combustion pressure, the greater is the indicated power and the better the combustion status. However, limited by engine strength and mechanical efficiency, the maximum combustion pressure should not be too high. The maximum combustion pressure and the crank angle are used to show whether the combustion of engine is in time or not.

Figure 2 shows the result of the combustion process when oxygen concentration is 21% and 24% respectively, from which it may be found that, as the oxygen concentration in the intake air is increased, the maximum value of cylinder pressure is increased, and the time that the maximum value of pressure is reached is advanced. When oxygen concentration is 21%, the maximum cylinder pressure measured was 21.239 bars. At that moment, the crank angle was 117°. When oxygen concentration was increased to 24%, the maximum cylinder pressure measured was 24.493 bars, and at that instant the crank angle was 63°. The relative increase in cylinder pressure is not very much, but the maximum pressure value was reached earlier with the increase in the ratio of oxygen. This occurred because the fuel was able to combust more completely due to the increase in oxygen concentration. The amount of heat produced was also increased, which led to an increase in cylinder pressure. Additionally, the fuel was able to combust faster and flame velocity was reached more quickly, therefore the time of maximum pressure was reached earlier.

*B. Study of the Rate of Change of Cylinder Pressure*

The maximum rate of increase of pressure and its corresponding crank angle were recorded. The maximum rate of pressure increase is related to the rate of combustion. If the rate of combustion is too fast, the engine will run very roughly, while a combustion rate that is too slow will result in poor power and poor fuel economy. Oxygen in the air at intake has a large influence on the rate of combustion and the flame velocity. Therefore, the research shows there is justification to use changes in the maximum rate pressure increases to reflect the influence of oxygen concentrations in the intake air on the properties of combustion, and the characteristics of an engine.

Figure 3 shows the rate of change of the cylinder pressure during the combustion process when the oxygen concentration reaches 21% and 24%, respectively. From this, it can be seen that the maximum value of the rate of change of cylinder pressure is 0.789 bar/°CA and the corresponding crank angle is 107°, when the oxygen concentration in the intake air is 21%. The maximum value of rate of change of cylinder pressure rise rate is 1.287 bar/°CA and the corresponding crank angle is 58°, when the oxygen concentration in the intake air is 24%. As the same, due to the increase of oxygen entering the cylinder, the fuel combusts more quickly and the flame velocity is increased, both of which have lead to an increase in rate of change of pressure and a quicker time to reach the moment of maximum value the rate of change of pressure. Accordingly, in order to reduce the deflagration trend of engines, the ignition advance angle should be delayed or postponed appropriately when oxygen concentration in the intake air is increased.

*C. Study of Heat Release*

Heat Release Law is achieved by calculation from the measured indicator according to the thermodynamic *Law of Conservation Of Energy* and the *Law of Conversion of Energy* under a given hypothesis. It may reflect more accurately the property/characteristics of a combustion process. Therefore, it is an effective way to evaluate the combustion process of an engine under different concentrations of oxygen in the intake air, and to research and analyze the combustion process in an engine by using the heat release law. In this paper, the combustion performance of an engine is influenced by oxygen concentration in the intake air, and two aspects of the combustion process are analyzed: heat release and the rate of heat release.

Figure 4 shows a comparison of heat release during the fuel combustion process at oxygen concentrations of 21% and 24% respectively. From this, we find that the maximum value of heat release of fuel during the process of combustion is 1.858%/°CA with a corresponding crank angle of 89.5° when the oxygen concentration is 21%. And the maximum value of heat release of fuel is 2.759%/°CA with a corresponding crank angle of 58° when oxygen concentration is 24%. Meanwhile, the initial time/moment of heat release is advanced and the maximum value of heat release due to combustion is increased. Due to an increase in oxygen concentration, same amounts of fuel will combust more completely， or the fuel sprayed into the cylinder within the same amount of time is increased and such leads to an increase of heat released during the combustion process. As a result, due to the increase of oxygen concentration, the fuel can be combusted more rapidly, the flame velocity becomes faster and initial time of heat release is advanced.

*D. Study of the Rate of Cycle Alteration During the Combustion Process*

The cyclic variations of combustion are constantly changing during the combustion process between the first circulation and the next when an engine is operating under given stable working conditions. Its result is that the pressure curve, flame propagation and engine's power output are different. Cyclic variations in combustion have an unfavorable influence on the engine and lead to overall deterioration of engine's performance in power, fuel economy, emissions and maneuverability.

There are many factors that influence cyclic variations during the combustion process, of which the major factors include the cyclic variations of air movement in cylinder, the location of the flame center formed after spark ignition, the variations in the flame's initial growth rate due to changes in speed and direction of airflow velocity, and the content of gas mixture (especially the content adjacent to the spark plug at the moment of ignition).

The cyclic variation rate of maximum combustion pressure is used as the major parameter for evaluating cyclic variation in combustion. The equation for calculating the cyclic variation rate is:

$$\delta = \frac{P_{\max STD}}{\overline{P_{\max}}} \times 100\% = \frac{\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(P_{i\max} - \overline{P_{\max}})^2}}{\frac{1}{n}\sum_{i=1}^{1} P_{i\max}} \quad (1)$$

where $P_{maxSTD}$ is the standard deviation of maximum combustion pressure, $\overline{P_{\max}}$ is the averaged value of the maximum combustion pressure of $n$ continuous cycles. $P_{imax}$ is the maximum combustion pressure of cycle $i$, $n$ is the number of samples. The sample length during the experiment for this paper is 120 continuous cycles.