Impact of Traffic Flow on Pollution at Urban Intersections

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Abstract. Intersections are mainly considered as critical elements of road networks in terms of air quality impact, and their control type and geometric configuration can affect significantly vehicular emissions. This study aims mainly to investigate the effect of traffic flow on the level of pollution at a selected intersection in Kerbela city. Hence, the video camera has been installed for three normal days to investigate the traffic flow fluctuation for 24h. Then, Gasmet has been used for investigating the amount of emission for both CO2 and CO within the peak hour. A well-known SIDRA 8.0 has been used for analyzing the intersection. The results indicated that the CO2 is exceeded the acceptable limit with worse traffic operations for both selected intersections.

Keywords: Traffic pollution, CO2 and CO, Signalized intersection, SIDRA

1. Introduction

Air pollution produced by vehicular traffic has become a serious problem for traffic engineers. Vehicular emissions depend on traffic, road and vehicle characteristics, atmospheric conditions, and driving behavior. Intersections are critical elements of road networks in terms of air quality impact, and their control type and geometric configuration can affect significantly vehicular emissions. At intersections vehicles usually slow down and often stop, thus interrupting traffic flow in varying patterns [1].

Daily travel may contribute a disproportionate fraction of the overall inhalation of air pollutants for urban populations, and may vary considerably according to the travel mode choice. Due to the proximity to traffic, transportation microenvironments can exhibit relatively high concentrations, which are compounded by high inhalation rates in the case of active travel (walking and cycling). Traffic-source air contaminants, furthermore, tend to reach their peak during typical morning commute times [2].

The environmental pollution caused by motor vehicles has increased substantially, particularly in urban areas, mainly as a result of the continual rise in vehicle numbers. In the long-term, only extremely strict exhaust gas standards will allow for a pollution reduction. But in any case, it is necessary to evaluate the emission of hazardous substances caused by road traffic. Evaluations are even more important if changes are planned which will cause modification of emission rates. Among those interventions which are directly related to road traffic, the changes in the road network can be
counted, and among indirectly related changes there are the building of infrastructure objects, which will emit the same substances as the road traffic. With the emission analysis, Rebolj and Sturm [3] reported that the influence of a specific location for a plant, which will emit the same hazardous substances as the road traffic, to the total concentration of those substances, the road design variant which causes minimal emission of hazardous substances and finally, the relations between traffic changes and emissions.

For the road traffic emission analysis, the dispersion of emitted substances into the area are required, whereby more or less relevant micro and macro parameters are considered (temperature and wind conditions, terrain configuration, etc.). This is known as a dispersion model (or emission model in some parts of the world) [3].

2. Traffic pollution
Traffic-generated air pollution is of great concern to the general public. Motor vehicles emit nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOC), and particulate matter (PM), which constitute a major source of air pollution in large cities. Traffic generated air pollutants, such as NO2 and PM, are of health concern; and traffic generated greenhouse gases, such as carbon dioxide (CO2), may contribute to global warming. As motor vehicles are the major contributor to urban air pollution, control strategies need to be developed that minimize the environmental impacts but maximize the efficiency of motorized transport [4].

Steady growth in vehicular populations has put environmental stress on urban centers in various forms particularly causing poor air quality. The severity of the problem arises when the traffic flow is interrupted and the delays and start–stops occur frequently. These phenomena are regularly observed at traffic intersections, junctions, and signalized roadways. As a result queuing of vehicles, stopped-delay at the signals, rates of traffic flow in various idle, acceleration, deceleration, and cruise driving modes, and frequent interruptions often occur. These traffic-related characteristics, combined with road and vehicle characteristics, raise emissions at traffic intersections [5].

The environmental aspects of an intersection design are highly neglected in the planning and construction processes. The emission and exhaust levels at intersections could be much higher than at the links between. For example, it has been observed that pollution concentrations are highest near traffic junctions [6], where queuing occurs. It is also known that the present vehicle engine gives a significantly lower contribution to the total air pollution when working at constant reasonable speed than during acceleration, stopping, and at low speeds. Therefore there are emission distributions along the urban roads, which could not be considered constant. Matzoros [7] gives two reasons for the uneven distribution of emissions along the streets. One is that vehicles spend longer periods near junctions queuing, decelerating, and accelerating and the other is that the transient operating modes themselves are generally more polluting than unobstructed cruising.

The vehicle emission models are affected by three main aspects which are vehicle design and condition, traffic volume and its composition (proportion of heavy vehicles), and road specifications [8]. Recently, environmental considerations have become an essential part of the planning process besides engineering and economics [9]. It is well known that Carbon monoxide (CO) is considered an extremely unhealthy gas. CO results from the incomplete combustion fuel. CO could be produced by car equipment those operated by internal combustion engines, and its concentration measured in parts per million or ppm [10].

Traffic congestion is costing time and resources and the risk of accidents and localized pollutants such as particulates is increased. Perhaps the most serious, though the least immediate, the consequence of traffic congestion is possibly increased greenhouse gas emissions. Although many people understand that driving leads to greenhouse gas emissions, the calculation of this effect has been surprisingly blunt, frequently associating carbon emissions with trip distance only, without taking into account how vehicle speed shifts in carbon emissions [11].
Gas emission depends on speed, acceleration, and vehicle performance level (performance index for passenger car units and trucks). The fuel consumption and emission change according to speed rate: for idling rate ≤50% of total emission, for accelerating rate=35-40% of total emission and for decelerating rate ≤10% of total emission [12].

Emission rates depend on the characteristics of traffic, vehicles, and type of road intersections. For example, the type, size, age of a vehicle, and condition of its engine, type, and condition of emission control equipment, engine characteristics, vehicle maintenance, and weight, all correlate to the emissions. Engine size also affects the functioning of emission control equipment [13].

Age of a vehicle and the poor maintenance adds to the emissions of all classes of vehicles. Further, fuel quality has a direct effect on vehicular exhaust emission [14].

Particle emissions from vehicles occur mainly from the exhaust pipe, from brakes, tires, and through re-suspension of particles on the road. The class of a vehicle and the type of fuel used also influences the concentration of this pollutant, being heavy vehicles a big contributor due to weight and a greater area of tires, releasing particles from tires and through re-suspension. Diesel vehicles are also an important source due to incomplete combustion and to the composition of the fuel itself [15].

Road and street intersections force vehicular traffic to slow down and stop in varying patterns of interruption of ideal, constant traffic flow at an ideal speed. The longer the stops, the more fuel that is consumed and vehicular emissions increase. With the vehicular emissions problems worsening, it has become prudent to choose effective traffic control devices that can improve traffic flow on the roads and, reduce emissions per vehicle kilometer traveled while enhancing mobility [16].

Hallmark et al, [17] used a vehicle instrumented with a Portable Emission Measurement System (PEMS) to collect on-road pollution data and compared the air quality impacts of different types of intersections (signal-controlled, four-way stop, and roundabout). Based on the analysis of CO2, CO, NO, and HC emissions, the authors concluded that roundabouts do not necessarily perform better than the other forms of intersection control. They also suggested that the results varied by type of pollutant and stressed the effect of driver behavior.

Papson et al., [18] used a time-in-mode analysis to estimate vehicular emissions at a signalized intersection under different traffic scenarios. Their results show that emissions are much less sensitive to congestion than control delay and that significant environmental benefits can be expected from strategies (like signal coordination) that reduce the time spent by vehicles in the acceleration mode.

The main objective of this study are investigate the effect of traffic flow on the level of pollution at a selected intersection in Kerbela city.

3. Methodology
The main steps of this study could be summarized as: firstly, it is to select the study area for an urban intersection. Then, the required traffic and pollution data have been collected using the video camera and Gasmet instrument. This instrument has been used for collecting data of CO2 and CO. Besides, SIDRA 8.0 software has been used to find out the performance of the signalized intersections to find out the effect of LOS over the gas emission. Finally, the relationship between flow and pollution would be investigated.

4. Software Selection
SIDRA software is used for data analysis. This software developed by the Australian Road Research Board (ARRB) to evaluate the traffic performance of signalized intersections, SIDRA is a micro-analytical software, which is widely used in traffic engineering for a lane-by-lane analysis of different intersection types. It uses traffic models coupled with an iterative approximation method to provide estimates of measures of effectiveness (MOE) such as intersection capacity, total delay, queue lengths, and Level of service [19].
5. Study Area
Karbala is one of the special cities in the Islamic world. It is famous due to its religious aspect. The old city, or city center, is holding the holy shrines of Imam Hussain (the grandson of the Holy Prophet of Islam) and his stepbrother Abbas. It lies between (41° , 10’) to (44° , 20’) longitude and (32° ) to (31° ) latitude, departed at about 110 km south-west away from Baghdad as shown in Figure 1.

![Figure 1: Location of Karbala City and its Satellite Image](image)

6. Description of the study area
The study area has two intersections ( AL-Dhareeba intersection and Police Central Al-Hussein Neighborhood intersection ) which are signalized intersections.
AL-Dhareeba is one of the most important intersections located in the center of Kerbala city with a four-leg signalized intersection as shown in Figure 2. It is a significant location with a high volume. This intersection suffers from heavy traffic congestion. Whereas, Central Al-Hussein intersection is a four signalized intersection as indicated in Figure 3.
Figure 2. AL-Dhareeba intersection

Figure 3. Central Al-Hussein intersection.

7. Data collection stage
Data have been collected from the field using the video camera, videotaping method is preferable for many reasons including:
- The ease of collecting data.
- A large number of situations can be recorded clearly.
- The collected data can be revised and analyzed in more detailed at any time.
- Data including traffic flow, capacity, and all the maneuvers can be extracted visually from the videotapes.

The camera used has the following specifications:
• 2 Megapixel high-performance
• Analog HD output with up to 1080p resolution
• Day/Night switch

The cameras have been installed on the overhead bridge carrying the traffic signals as indicated in Figure 4. Many considerations should be taken into account while recording such as good weather and good visibility condition.

Figure 4. The location of cameras in the study area.

8. Traffic Volume Data
These data include counting the traffic volumes extracted from video recording for each approach at the intersections in the selected network, four cameras were installed one camera on each approach to the intersection during peak hours, traffic count was achieved on (30 /1/2021) for the period from (8:30 AM to 10:30 AM), the network traffic flow rate for AL-Dhareeba intersection and Police Central Al-Hussein Neighborhood intersection as shown in Tables 1 to 6.

Table 1. Traffic flow rate (veh/hr) for each approach for (AL-Dhareeba intersection )

| Time       | NB  | SB  | EB  | WB  | Flow rate |
|------------|-----|-----|-----|-----|-----------|
| 8:30-8:45  | 1220| 1336| 400 | 1052| 4008      |
| 8:45-9:00  | 1276| 1260| 416 | 976 | 3928      |
| 9:00-9:15  | 1424| 1320| 428 | 1092| 4264      |
| 9:15-9:30  | 1184| 1548| 460 | 868 | 4060      |
| 9:30-9:45  | 1452| 1536| 500 | 976 | 4464      |
| 9:45-10:00 | 1348| 1616| 460 | 896 | 4320      |
| 10:00-10:15| 1220| 1336| 400 | 1052| 4008      |
| 10:15-10:30| 1276| 1260| 416 | 976 | 3928      |

In this study, the following abbreviations have been used which are NB, SB, EB, and WB that represent north, south, east and west bounds, respectively. Similarly, RT, TH and LT represent right turn, through and left turn movements.
The peak flow for AL-Dhareeba intersection is 4464 veh/hr; whereas for Central Al-Hussein intersection is 5568 veh/hr as indicated in Tables 1 and 4. Then, the percentage of heavy vehicle (HV%) is also indicated for both sites in Tables 3 and 6.

Table 2. Flow rate (veh/hr) for all movements for AL-Dhareeba intersection

| Time      | NB   | SB   | EB   | WB   |
|-----------|------|------|------|------|
|           | RT   | TH   | LT   | RT   | TH   | LT   | RT   | TH   | LT   |
| 8:30-8:45 | 496  | 616  | 108  | 236  | 752  | 348  | 152  | 68   | 180  | 460  | 228  | 364  |
| 8:45-9:00 | 408  | 788  | 80   | 236  | 684  | 340  | 152  | 76   | 188  | 452  | 244  | 280  |
| 9:00-9:15 | 436  | 876  | 112  | 232  | 648  | 440  | 208  | 60   | 160  | 512  | 264  | 316  |
| 9:15-9:30 | 468  | 600  | 116  | 308  | 932  | 308  | 192  | 28   | 240  | 532  | 60   | 276  |
| 9:30-9:45 | 448  | 852  | 152  | 304  | 796  | 436  | 188  | 88   | 224  | 580  | 80   | 316  |
| 9:45-10:00| 472  | 748  | 128  | 344  | 916  | 356  | 152  | 28   | 280  | 516  | 84   | 296  |
| 10:00-10:15| 564 | 868 | 136  | 368  | 920  | 428  | 212  | 56   | 264  | 648  | 200  | 368  |
| 10:15-10:30| 556 | 856 | 172  | 376  | 924  | 500  | 228  | 168  | 340  | 604  | 172  | 364  |

Table 3. HV rate (veh/hr) for each approach for AL-Dhareeba intersection.

| Time      | Approach | Flow rate | HV% |
|-----------|----------|-----------|-----|
| 8:30 - 8:45 | NB       | 256       | 136 | 36 | 228 | 656 | 16.36 |
| 8:45 - 9:00 | SB       | 236       | 96  | 24 | 216 | 572 | 14.56 |
| 9:00 - 9:15 | EB       | 256       | 176 | 20 | 200 | 652 | 15.29 |
| 9:15 - 9:30 | WB       | 216       | 188 | 40 | 176 | 620 | 15.27 |
| 9:30 - 9:45 |           | 232       | 164 | 16 | 216 | 628 | 14.07 |
| 9:45 - 10:00|           | 228       | 192 | 40 | 200 | 660 | 15.27 |
| 10:00 - 10:15|          | 204       | 172 | 48 | 248 | 672 | 13.35 |
| 10:15 - 10:30|          | 256       | 204 | 28 | 240 | 728 | 13.84 |

Table 4. Traffic flow rate (veh/hr) for each approach for (Central Al-Hussein intersection)

| Time      | Approach | Flow rate |
|-----------|----------|-----------|
| 8:30 - 8:45 | NB       | 1868      | 2384 | 616 | 576 | 5444 |
| 8:45 - 9:00 | SB       | 2028      | 2172 | 508 | 508 | 5216 |
| 9:00 - 9:15 | EB       | 1760      | 2536 | 616 | 620 | 5532 |
| 9:15 - 9:30 | WB       | 1724      | 1776 | 620 | 536 | 4656 |
| 9:30 - 9:45 |           | 1912      | 1924 | 504 | 720 | 5060 |
| 9:45 - 10:00|           | 1368      | 2332 | 648 | 636 | 4984 |
| 10:00 - 10:15|         | 1684      | 2620 | 672 | 592 | 5568 |
| 10:15 - 10:30|         | 1724      | 2440 | 588 | 744 | 5496 |
Table 5. Flow rate (veh/hr) for all movements for Central Al-Hussein intersection

| Time     | NB | SB | EB | WB |
|----------|----|----|----|----|
| 8:30-8:45 | 1204 | 656 | 112 | 1884 | 388 | 286 | 44 | 196 | 184 | 136 | 256 |
| 8:45-9:00 | 1460 | 560 | 72 | 1760 | 340 | 332 | 84 | 92 | 188 | 188 | 132 |
| 9:00-9:15 | 1268 | 484 | 124 | 1804 | 368 | 416 | 112 | 88 | 248 | 164 | 208 |
| 9:15-9:30 | 1172 | 552 | 100 | 1500 | 416 | 388 | 148 | 84 | 228 | 112 | 196 |
| 9:30-9:45 | 1340 | 568 | 128 | 1444 | 352 | 292 | 136 | 76 | 312 | 172 | 236 |
| 9:45-10:00 | 948 | 416 | 100 | 1880 | 352 | 388 | 168 | 92 | 264 | 180 | 192 |
| 10:00-10:15 | 1220 | 456 | 100 | 1748 | 352 | 488 | 88 | 96 | 228 | 164 | 200 |
| 10:15-10:30 | 1168 | 552 | 180 | 2172 | 508 | 400 | 60 | 128 | 300 | 180 | 264 |

Table 6. HV rate (veh/hr) for each approach for (Central Al-Hussein intersection)

| Time     | NB | SB | EB | WB | Flow rate (veh/hr) | HV% |
|----------|----|----|----|----|-------------------|-----|
| 8:30-8:45 | 396 | 344 | 68 | 100 | 908 | 16.67 |
| 8:45-9:00 | 388 | 276 | 60 | 72 | 796 | 15.26 |
| 9:00-9:15 | 312 | 316 | 72 | 80 | 780 | 14.73 |
| 9:15-9:30 | 532 | 380 | 72 | 60 | 1044 | 21.32 |
| 9:30-9:45 | 200 | 276 | 76 | 80 | 632 | 12.49 |
| 9:45-10:00 | 324 | 408 | 64 | 84 | 880 | 17.65 |
| 10:00-10:15 | 396 | 332 | 84 | 76 | 888 | 17.24 |
| 10:15-10:30 | 340 | 492 | 96 | 84 | 1012 | 17.10 |

9. Pollution Data

Air pollution due to vehicle traffic is a complex mixture of gaseous compounds and particles that can be directly emitted from fuel combustion (e.g., NO, CO, CO2, diesel-exhaust particles); from brake wear, tire wear, and resuspended particles (e.g., trace metals); or formed through physical and chemical processes (e.g. ozone, NO2, secondary aerosols). The pollutant mixture can vary considerably as well as decrease sharply in concentration within short distances moving away from traffic [20].

Due to the importance of gas emissions (CO, CO2), the pollution data were calculated using (GASKET DX4040) device. Gas emissions were achieved on (30/1/2021) for the period from (8:30 AM to 10:00 AM) at the same time traffic volumes were calculated. Tables 7 and 8 reveal the pollution data for the intersections in the study area.

The Gasmet DX4040 FTIR gas analyzer can detect up to 25 gases simultaneously providing validated results in 25 sec. Fourier Transform Infrared Spectroscopy (FTIR) provides reliable measurements with low detection limits & true multi-compound analysis capability. The library of measured gases can be changed by the user through an easy-to-use interface, providing exceptional flexibility and the ability to respond to any measurement requirement in the field.[21]

Measurement with the DX4040 is easy; sample gas is drawn into the analyzer with a built-in pump through a handheld particle filter and Tygon tubing. The analyzer runs in continuous mode, measuring time-weighted averages of user-definable length from 1 second to 5 minutes. The Gasmet DX4040 is capable of sub-ppm detection without using sorbent traps for sample pre-concentration, which guarantees fast response times. Zero calibration with clean air or nitrogen is the only calibration required, carrier gases, special test gases, or other consumables are not needed, the device is shown in Figure 5. The suggested Iraqi limits of CO2 and CO are 300ppm and 35ppm, respectively [22].

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The Gasmet has been used together with a video camera to collect the synchronized flow rate passing through the intersection, where the location of the device was chosen based on the directions of the expert who carried out the examination, who specializes in choosing the best site for the device to measure pollution, which is at a height of a 1 meter and as shown in Figure 5. A technician person who implemented the test. The test has lasted for 90 minutes as indicated in Tables 7 and 8.

**Figure 5.** GasmetDX4040 devices

### Table 7. Pollution data for AL-Dhareeba intersection.

| Time | CO2 (ppm) | CO (ppm) |
|------|-----------|----------|
| 8:30-8:45 | 407.8 | 1.06 |
| 8:45-9:00 | 419 | 0.78 |
| 9:00-9:15 | 438 | 1.23 |
| 9:15-9:30 | 449.5 | 2.43 |
| 9:30-9:45 | 452.8 | 2.7 |
| 9:45-10:00 | 459.7 | 2.9 |

### Table 8. Pollution data for Central Al-Hussein intersection.

| Time | CO2 (ppm) | CO (ppm) |
|------|-----------|----------|
| 8:30 - 8:45 | 470 | 6.31 |
| 8:45 - 9:00 | 476 | 5.73 |
| 9:00 - 9:15 | 478.39 | 4.26 |
| 9:15 - 9:30 | 469.43 | 3.62 |
| 9:30 - 9:45 | 462.94 | 2.49 |
| 9:45 - 10:00 | 456.32 | 1.95 |

**10. Discussion**

After collecting flow data and pollution data as mentioned previously, the relationship of flow and pollution gases (CO2 and CO) has been investigated as shown in Figures 6 and 7 Al-Hussein and
AL-Dhareeba intersections. However, these relations are approximately increasing with flow increasing in general trend but a lot of factors that may govern this relationship such as wind speed and the weather temperature which can be difficult to control.

![Graph](image1)

**Figure 6.** Traffic flow rate impact on CO\(_2\) for Al-Hussein and AL-Dhareeba intersections.

![Graph](image2)

**Figure 7.** Traffic flow rate impact on CO for Al-Hussein and AL-Dhareeba intersections.

On the other hand, the analysis of performance for both intersections using SIDRA 8.0 reveals that the LOSF indicated that both intersections work at a congestion state. A detailed analysis for each
15 minutes has been done to know how the LOS changes with pollution level as indicated in Tables 9 and 10 for both intersections. The highest delay for the Central Al-Hussein intersection shows the highest level of pollutions for both CO2 and CO as indicated in Tables 9 and 10.

| Time       | Flow rate (veh/hr) | LOS | Control delay (Average) |
|------------|--------------------|-----|--------------------------|
| 8:30-8:45  | 4008               | F   | 404                      |
| 8:45-9:00  | 3928               | F   | 378.2                    |
| 9:00-9:15  | 4264               | F   | 478.8                    |
| 9:15-9:30  | 4060               | F   | 486.7                    |
| 9:30-9:45  | 4464               | F   | 486.7                    |
| 9:45-10:00 | 4320               | F   | 548.2                    |

| Time       | Flow rate (veh/hr) | LOS | Control delay (Average) |
|------------|--------------------|-----|--------------------------|
| 8:30-8:45  | 5444               | F   | 836.5                    |
| 8:45-9:00  | 5216               | F   | 769.4                    |
| 9:00-9:15  | 5532               | F   | 813.7                    |
| 9:15-9:30  | 4656               | F   | 704.3                    |
| 9:30-9:45  | 5060               | F   | 711.3                    |
| 9:45-10:00 | 4984               | F   | 693.7                    |

11. Conclusions

The main conclusions from this study could be summarized as:
1. As traffic flow increases at an intersection, the pollution levels in terms of CO2 and CO increase.
2. The Iraqi limits for CO2 for both intersections are exceeded the acceptable limits, whereas the CO values are within the acceptable limits.
3. The LOS for both intersections is LOS F with a high level of control delay according to SIDRA 8.0.

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