RSS 2022
8th Road Safety & Simulation International Conference
Road Safety and Digitalization
08-10 June 2022 • Athens, Greece

University of Dayton

Assessing Different Freeway Interchange Design Impacts on Traffic Emissions and Fuel Consumption Through Microsimulation

Fayezeh Samandi, F.E, Engineer I, Ohio Department of Transportation, Columbus, OH, USA.

Deogratias Eustace, PhD, P.E., PTOE, Professor, University of Dayton, Dayton, OH, USA.

Samwel Ovier Zephaniah, Project Manager, Sheladia Associates, Inc., Rockville, MD, USA.

Philip Appiah-Kubi, PhD, Associate Professor, University of Dayton, Dayton, OH, USA.

Introduction

- Interchanges are critical locations with higher likelihood of crashes due to increased traffic conflicts on those areas.
- In designing those elements, the attentions are usually on two MOEs, safety and operational performances.
- However, their control type and geometry can have a significant impact on air quality,
- Recently the issue of emissions from transportation sector has drown so many attentions.
- This value can vary depends on traffic, road and vehicle characteristics, atmosphere conditions, and driving behaviors.

Introduction…

- In this study, the environmental performance of an existing service interchange, a Conventional Dimond Interchange (CDI), is compared with two other different popular alternative designs.
- These are: a Diverging Dimond Interchange (DDI) and a Single Point Urban Interchange (SPUI).
- The comparison is done in terms of fuel consumptions, emissions, and traffic operations through microsimulations analysis utilizing PTV Vissim.
- We are primarily focused on major pollutants, that is, CO_2, CO, and NO_x.

Introduction…

- Climate change and global warming observed in recent years are most likely the result of human activities.
- These are primarily due to fossil fuel burning, which causes the increase of the heat-trapping Greenhouse Gases (GHGs), consequently raising the average global temperature of the earth.
- Transportation sector with 29% is the largest contributor to GHGs, for which on-road vehicles account for more than 80% of the emissions.
- The goal of this study was to conduct a comparative emission analysis of an existing service interchange, a CDI, with other two alternative designs, a DDI and a SPUI.

Data collection

- This study used actual and most current traffic data for a CDI located in Montgomery County in Ohio.
- This interchange is located at the intersection of I-75 and Austin Blvd, about 12 miles south of Downtown Dayton.
- The latest classified turning traffic data counted on December 5, 2019 and signal timing data were obtained.
- Data was provided by the Ohio Department of Transportation (ODOT).

Methodology

Signal Optimization

- PTV Vistro 2020 was utilized to optimize the intersections on each model.
- The two intersections of the existing CDI are fully actuated with four coordination patterns.
- The PM peak hour pattern was selected for this study.
- All the interchanges' characteristics, such the number of lanes, lane width, and gradient, assumed the same for all models.

Methodology…

Traffic Simulation Analysis

- PTV Vissim 2020 is a microscopic tool that models transport operations based on a second-by-second, behavior-based model.
- Wiedemann's 74 car-following models, suitable for urban traffic, were adopted in these simulations.
- The signals are controlled by RBC, "Ring Barrier Controller" in all the models.
- Three scenarios were analyzed for each interchange type, a 20% lower and higher volume along with the actual traffic counts (base).

Methodology…

- Visualization color scheme in Vissim were used to calibrate the existing CDI.
- The Heatmap was created based on the network's current speed attribute and compared with live Google Maps traffic and OHGO for the evening peak hour period (4:45-5:45 pm) for which our traffic counts were based on.
- Also, introducing four data collection points helped to check the throughput volume at each exit, which within 15% reduction, the traffic counts were acceptable.

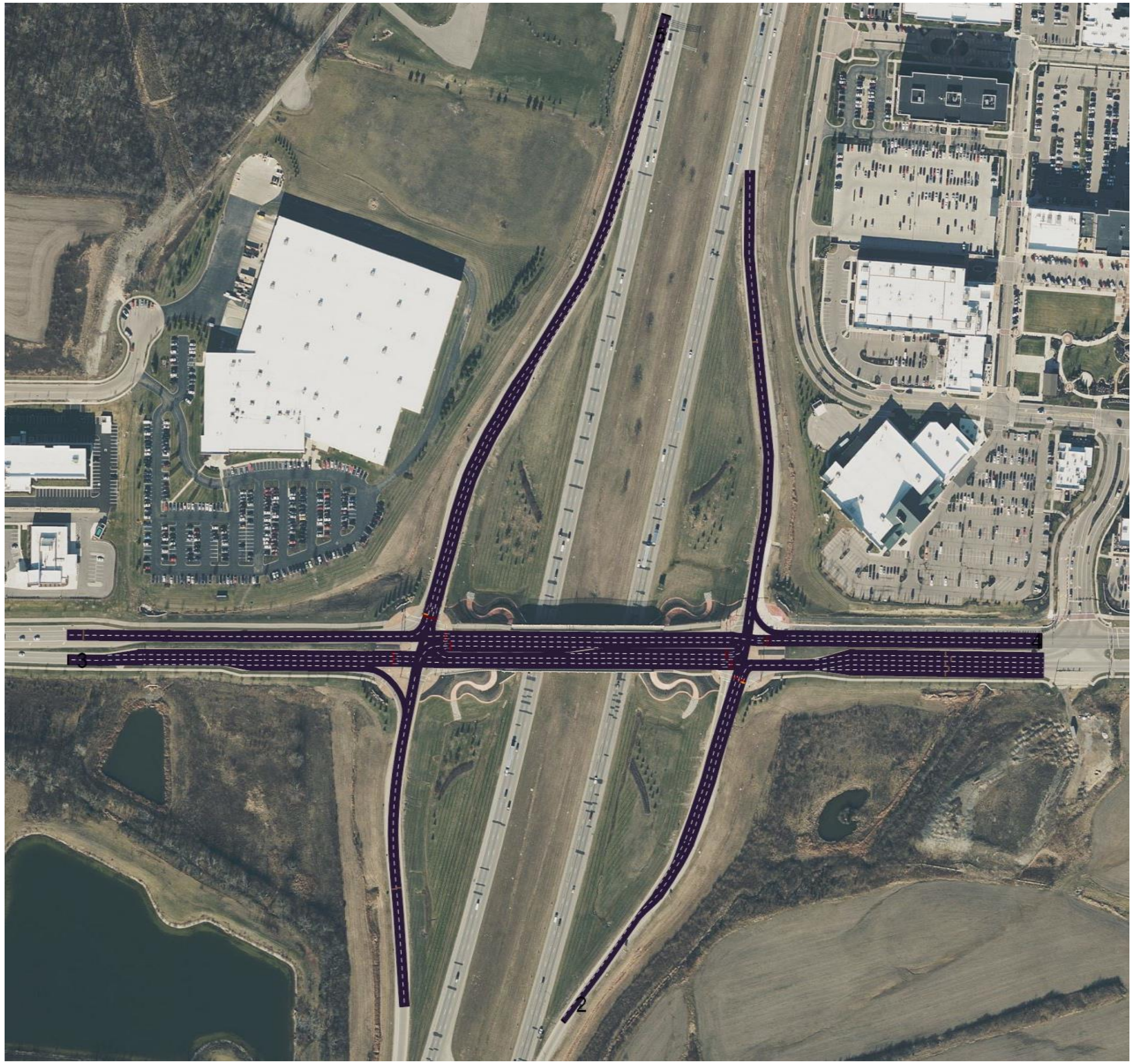
Methodology…

Emissions and Fuel Consumption Simulation Analysis

- In this study, we chose Vissim to calculate vehicles' exhaust emissions to assess the environmental impact (emissions).
- For emissions calculation, EmissionModel.dll as an external emission model was introduced to each vehicle type, which in this modeling we only have two vehicle types: (1) car and (2) heavy vehicle.
- Following parameters were transferred for all vehicles: accelerations, speeds, weights, ID numbers, vehicle types, and gradients.

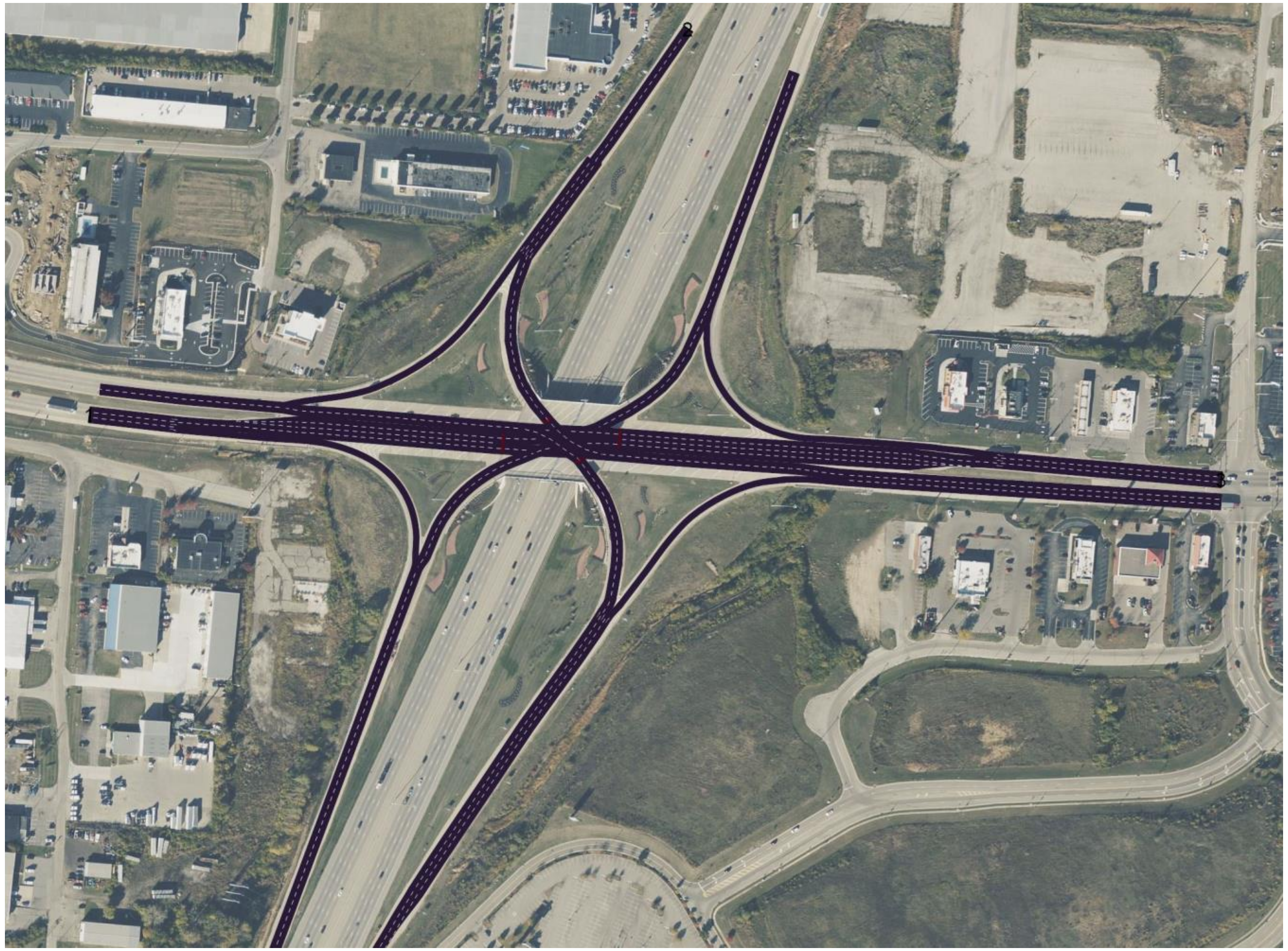
Methodology…

Existing CDI Design



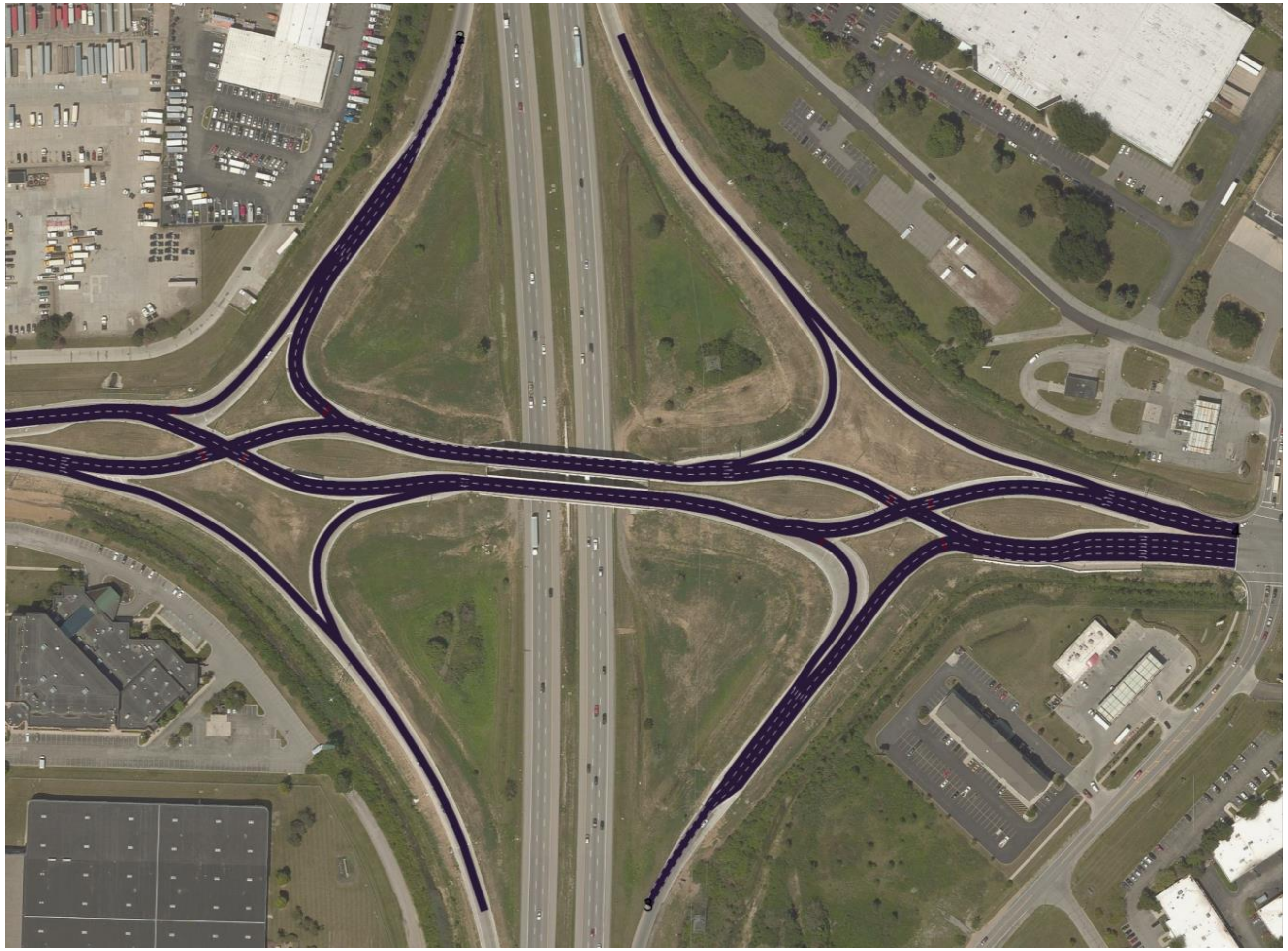
Methodology…

Proposed SPUI Design



Methodology…

Proposed DDI Design

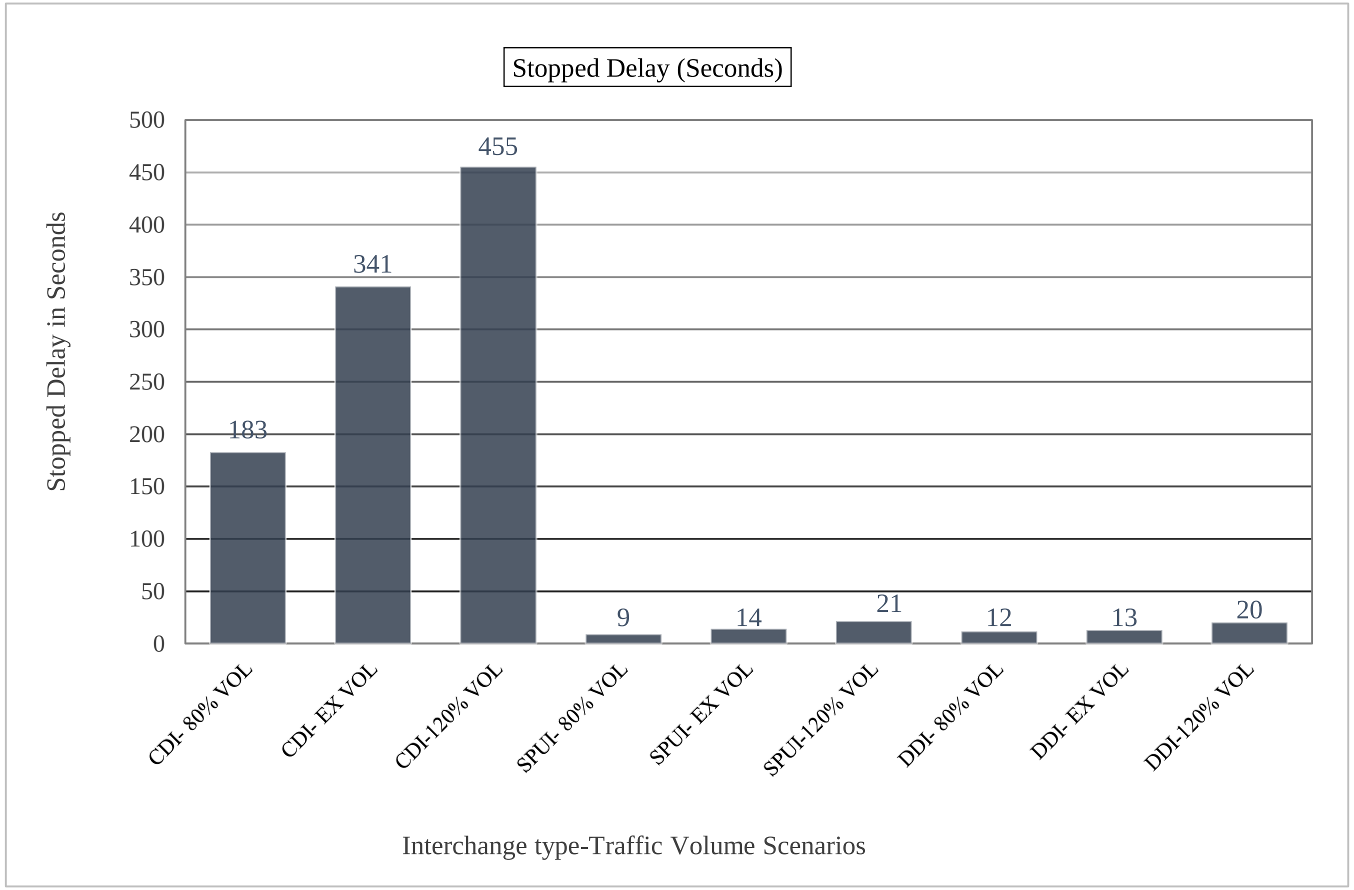


Results

- Two types of comparative results are presented:
  1. Operational Analysis Results: average queue lengths and average stopped delays
  2. Emissions Analysis Results (main study results):
     - ✓ CO_2 emission rates (grams/miles travel)
     - ✓ CO emission rates (grams/miles traveled)
     - ✓ NO_x emission rates (grams/miles travel)
     - ✓ Fuel consumptions (gallons)

Results...

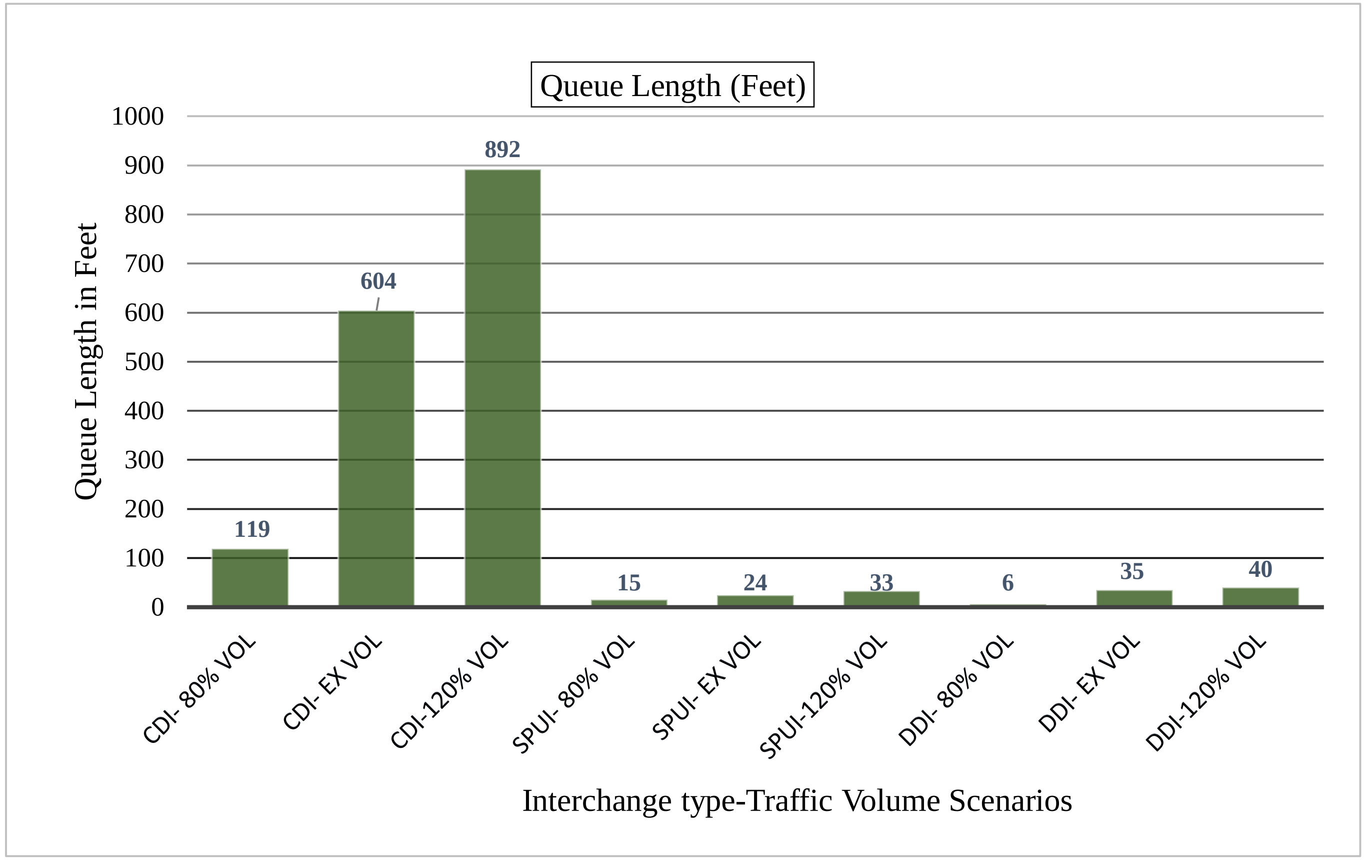
- Average stopped delay results (seconds)
  - ➢ For each interchange design type
  - ➢ And traffic loading scenario



Results...

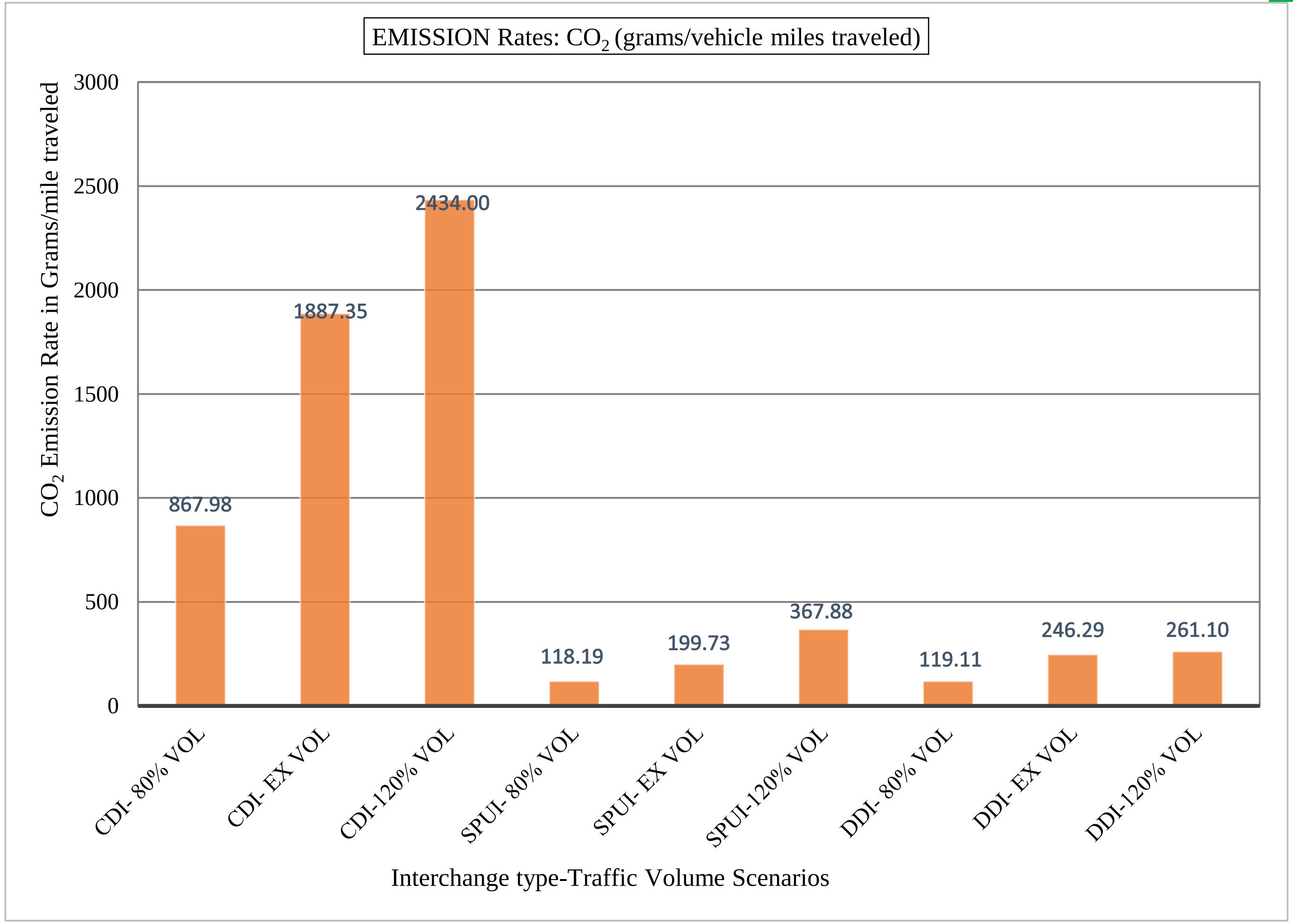
Average queue length results (feet):

- For each interchange design type
- And traffic loading scenario



Results…

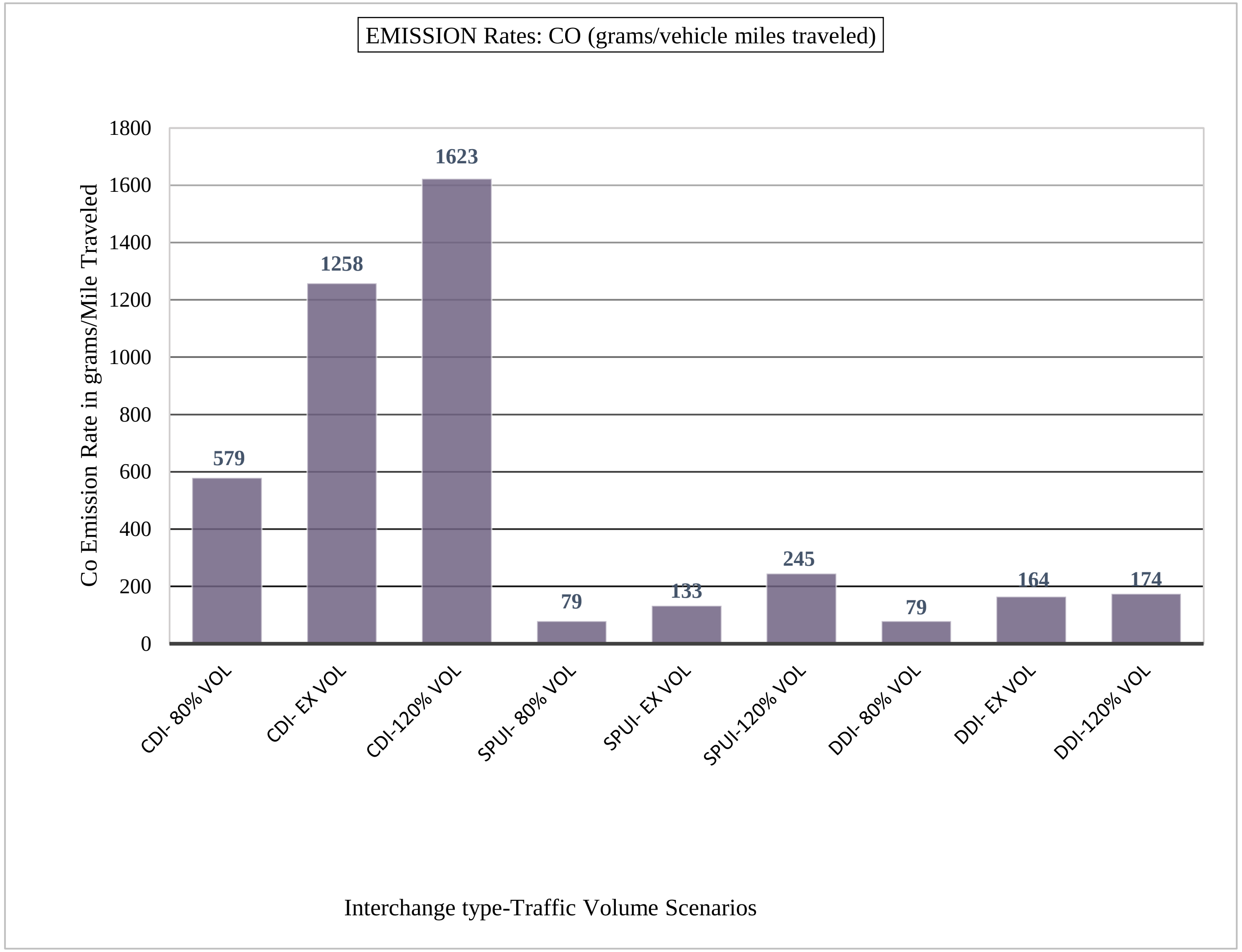
- Total CO_2 emissions (rate in grams/miles traveled)
  - ➢ For each interchange design type
  - ➢ And traffic loading scenario



Results...

Total CO emissions (rate in grams/miles traveled)

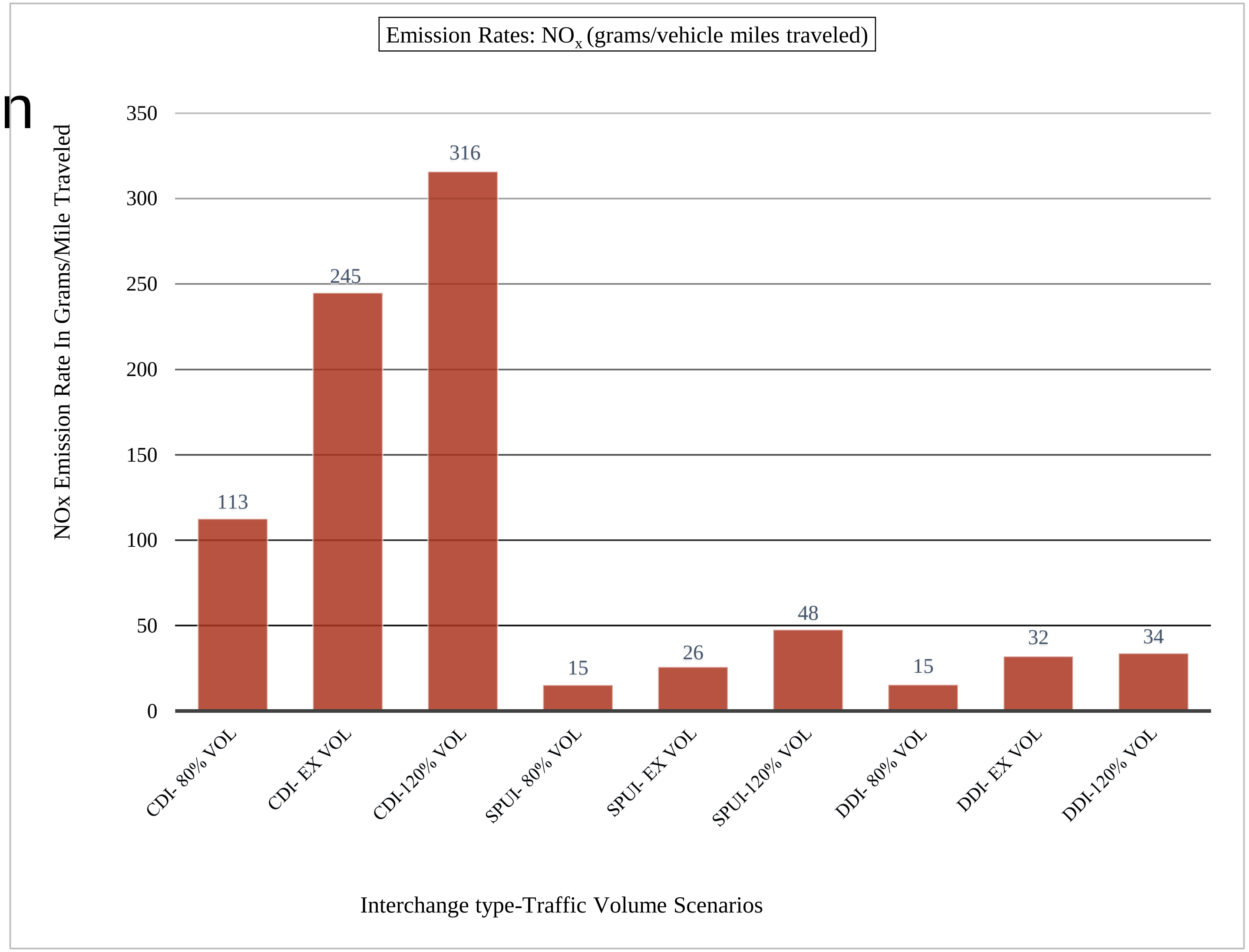
- For each interchange design type
- And traffic loading scenario



Results…

Total NO_x emissions (rate in grams/miles traveled)

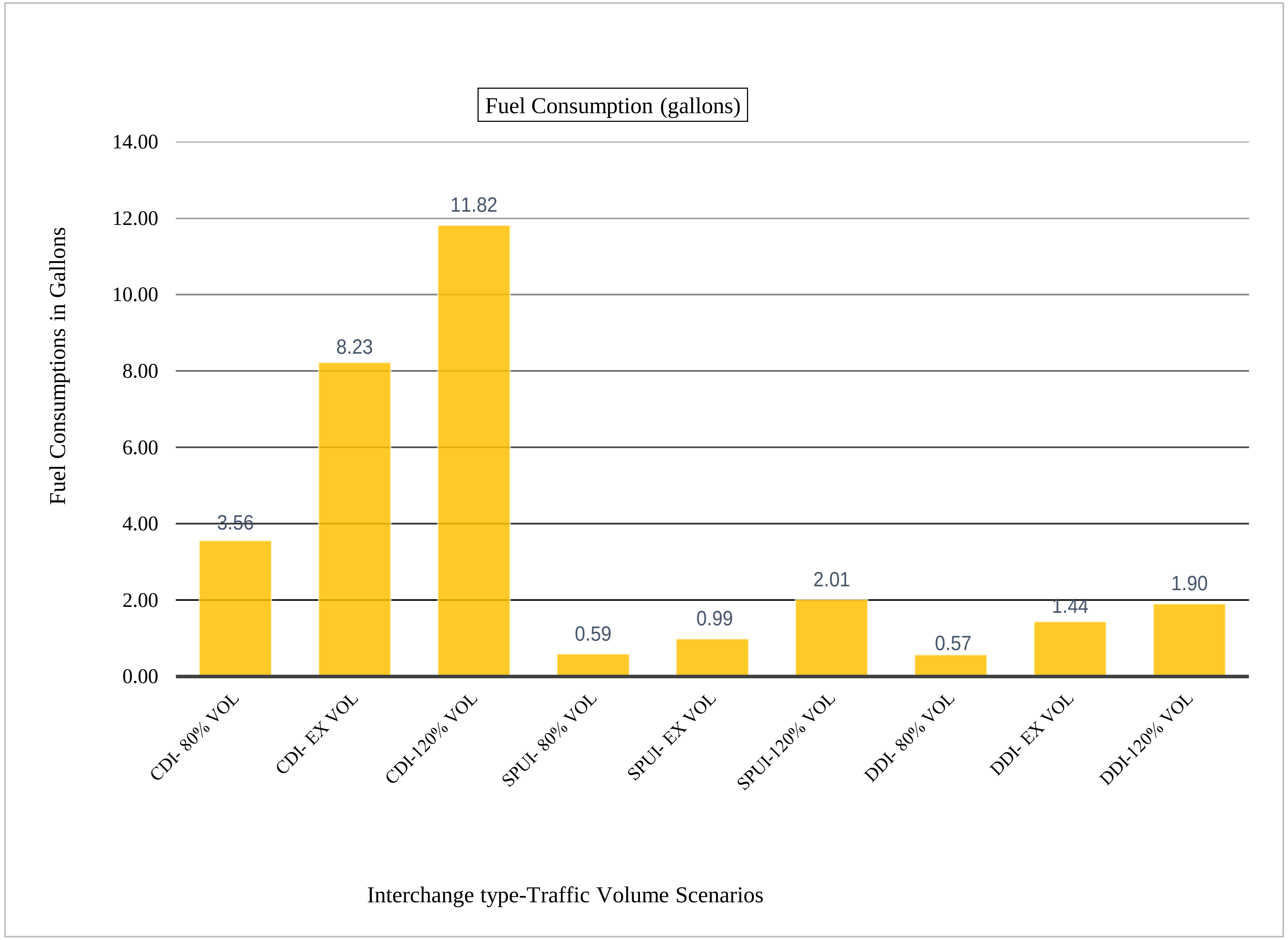
- For each interchange design type
- And traffic loading scenario



Results…

Total fuel consumption (gallons)

- For each interchange design type
- And traffic loading scenario



Discussion

- The emission results were directly exported from Vissim as Node Results and given in gram units.
- Each emission value was normalized by dividing the emission value by total vehicle mile travelled (VMT) for each scenario.
- This normalization makes it better to understand the relationships between the emission rates and the individual design alternatives.
- All emission results indicate that the existing CDI design results into much higher emission rates than the other two alternative designs, SPUI and DDI for each traffic level condition considered.

Results…

- A reduction in emissions of 85% on average for both alternative designs compared to the existing CDI was calculated.
- The different traffic levels (80%, 100%, and 120%) were developed to perform a sensitivity analysis to assess their impact on traffic operations and pollutant emissions for each design type studied.
- For a CDI, using the average queue length as a MOE, lowering the traffic volume by 20% lowered the average queue length by 80% and a 20% increase in traffic volume increased an average queue length by 48%

Results…

- For a SPUI design, lowering the traffic volume by 20% lowered the average queue length by 37% and a 20% increase in traffic volume increased an average queue length by 35%.
- For a DDI design, lowering the traffic volume by 20% lowered the average queue length by 83% and a 20% increase in traffic volume increased an average queue length by 15%.

Results…

- This queue length analysis shows that a DDI performed best at a higher traffic volume because it experienced the lowest increase when traffic volume was increased by 20%.
- In other words, we expect a DDI to perform better with congested traffic demand than the other two alternatives.
- For a CDI, lowering the volume by 20% resulted in an average reduction in all emissions and fuel consumption by 57% and a 20% increase in volume resulted in an average increase of 44% in emissions.

Results…

- For a SPUI, lowering the volume by 20% resulted in an average reduction in emissions by 40% and a 20% increase in volume resulted in an average increase of 104% in emissions rates.
- For a DDI design, lowering the volume by 20% resulted in an average reduction in emissions by 10% and a 20% increase in volume resulted in an average increase of only 11% in emissions.
- This again reveals that for a DDI, emissions tend to increase at a slower pace as volume increases.

Results…

- This study has shown that although the performances of the SPUI and DDI seem to be very close, in terms of emissions, the DDI performs much better than the SPUI at higher traffic volumes.
- In terms of layout design, although the DDI increases the distances traveled, still it improves the travel speeds and reduces stops and queue lengths compared to the other two design alternatives
- There is an important point to observe when interpreting the emissions assessment results from this study.
- The node emissions impact results in Vissim are based on TRANSYT 7-F, a program for optimizing signal times as well as data on emissions of the Oak Ridge National Laboratory of the U.S. Department of Energy.

Results…

- The methodology does not differentiate between individual vehicle types.
- Thus, the node evaluation is recommended for a simpler comparison of the emissions produced during different scenarios, similar to the current study
- Therefore, the results from the current study are good for comparing scenarios, not producing accurate emission values.

Conclusions

- Based on the results of this study, the DDI and SPUI have better performance in terms of average queue length and stop delays in the node's entire network (interchange area).
- They also perform at higher average speeds and with fewer stop delays than the existing CDI, resulting in a better level of service due to less congestion.
- Consequently, we observe much better emission rates and fuel consumption in alternative designs than the existing CDI.
- Although the SPUI's and DDI's performances are very close, the DDI design happens to result in lower emissions than the SPUI at higher traffic volumes (when the interchange is experiencing congestion).

Conclusions…

- A CDI seems to quickly result in operational and emissions problems as the traffic demand increases, thus underperforming CDIs should be considered to be replaced with DDIs or SPUIs.
- The emissions’ impacts of interchanges and other roadway designs are as significant as safety and operational performances when assessing the type of interchange design to implement during the planning and designing stages.
- The environmental impacts and air pollution need to be accounted for as we all hope to pass the gift of life to our next generations.

Questions ?