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Travel impacts of a complete street project in a mixed urban corridor

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Executive Summary

Complete streets facilitate multi-modal travel through human-centric infrastructure design with goals of improving safety and accessibility for all potential travelers. Examples include designing corridors with wide sidewalks, lighting, street furniture, adding bike lanes, improving transit shelters and turnouts, among others. This study evaluates the travel impacts resulting from a complete street redesign project through an urban corridor in Pittsburgh, PA. The retrofit project involved reducing vehicle lanes from four (two lanes in each direction) to three (one lane in each direction with a center turn lane) and adding dedicated bike lanes in each direction. The project also included new traffic signals, one new pedestrian crossing, reconfiguration and relocation of several intersections, improved bus turnouts, new pavement, and new street furniture. Before-and-after travel impacts (traffic counts and speeds, transit ridership, bicycle counts, air quality, and crash counts) were evaluated to quantify total benefits resulting from the retrofit project.

After project completion, reduced traffic counts were observed in both directions (eastbound and westbound) for both morning and evening peaks. The lower volume directions decreased by 11-21% and the higher volume direction (eastbound during evening peak) decreased by 31%. Traffic speeds through the corridor also decreased by 2.5-5.4mph (15-37%). Traffic speeds along a parallel corridor (Fifth Avenue) did not decrease, indicating that the project did not result in adverse network affects from traffic diversion.

Bicycle counts along the corridor increased 160% and 280% for morning and evening peak periods, respectively, after project completion. Transit ridership also increased, however, an upward trend in transit ridership was observed during the years prior to retrofit, thus making it difficult to attribute all bus ridership gains to the reconstruction alone. Average daily PM2.5 concentrations decreased from 9.1μg/m^3 to 7.6μg/m^3 after retrofit completion. PM2.5 concentrations before and after the project were well below the EPA standard of 12μg/m^3. Small changes in NO_2 and CO concentrations were also observed, and like PM2.5, concentrations of both NO_2 and CO remained well below standards set by the EPA. Crash counts did not increase during project construction indicating that no adverse effects were observed during construction. Crash counts did not increase after project completion; however, long-term monitoring will be required to draw any concrete conclusions regarding the safety impacts resulting from the complete street redesign. However, due to reduced traffic speeds and counts and the addition of pedestrian crossings, an increase in crashes during subsequent years is not expected.

Looking at the various impacts as one system, there is evidence of mode shift after project completion. Traffic counts through the corridor decreased while both bicycle traffic and bus ridership increased. Due to no changes in traffic speeds along the parallel corridor (Fifth Avenue), an inference can be made that traffic counts along this corridor remained unchanged after retrofit completion. Looking at these results holistically, it is likely that some mode shift is occurring if the overall counts of travelers remained unchanged during project duration.

More detailed project information and a more in-depth discussion of methods and results can be viewed in the journal publication listed in Appendix A.

1. Introduction

A reduction in urban motorist lanes, most commonly from four to three with a center turn lane and bicycle lane additions, has grown in popularity in recent years to reduce collisions and accommodate increased desire for active transportation. General trends extracted from 24 case studies show a reduction in accidents, increased pedestrian/cyclist counts, unchanged traffic counts, and a small increase in travel time for similar roadway narrowing projects (Federal Highway Administration 2017). Large variations in outcomes were observed across regions and for different built environments. In a different study based on six comprehensive assessments, total crashes reduced by 19% and 47% in urban and rural areas respectively (Thomas 2013). A study conducted along Ocean Park Boulevard in Santa Monica, CA resulted in unchanged traffic counts, however, vehicle type distribution shifted to a larger proportion of new light duty vehicles, which reduced on-roadway ultra-fine particulates (Shu, et al. 2014). Several other reports observed increased pedestrian and cyclist traffic after road conversion, however, it was difficult to determine if increased counts were due to recreational activity or mode shift (Shu, et al. 2014, Sallaberry 2000, City of Orlando 2002).

When road diet sections observed ADTs greater than 20,000 vehicles, it is estimated that neighboring streets will observe increased traffic volumes because congestion on the road diet section increased to a point where traffic begins to divert to alternate routes (Huang, Stewart and Zegeer 2002). After the completion of a road diet retrofit along Valencia Street in San Francisco, traffic volumes decreased by 10%. However, traffic volumes on parallel streets increased by 2-8%. The total ADT for all parallel streets increased by 1%, meaning that traffic, at least in the short term, chose alternative routes rather than shifting transportation mode (Sallaberry 2000). A different study along Telegraph Avenue in Oakland, CA found pedestrian and cyclist mode share increase from 8% to 16%. When including transit, mode share from these groups increased from 26% to 28% during peak demand. A bicycle intercept survey was conducted to understand greater network impacts, and 8% of the riders surveyed shifted travel modes after Telegraph Avenue reconstruction was complete (Fine and Tapase 2017). The remaining additional riders along Telegraph changed routes to utilize the protected bike lanes.

Conversion of motorist-centric 4-lane urban roadways to 3-lane designs focused on user choice can result in numerous community benefits. However, negative impacts such as increased congestion and travel time can occur when traffic volumes are high. Since project location, existing infrastructure and public transit options affect project outcomes in diverse ways, local analysis is required to accurately quantify benefits and provide insight for future decision making

Since 2012, and consistent with the CMU Institutional Master Plan, several planning studies have been conducted to support the reconfiguration of the Forbes Avenue arterial and corridor. These studies have examined different geographic areas, with the most extensive including Forbes and Fifth Avenues from Margaret Morrison to the Birmingham Bridge. These studies are significant because the Forbes and Fifth corridor in Oakland support about 100,000 residents, workers, and students per day. In 2018, a major reconfiguration will be implemented in the heart of CMU's campus along Forbes Ave between Margaret Morrison and Craig Street. Key features designed (by the CMU Campus Design and Facilities Development organization and GAI Consultants in collaborative funding with SPC and PA DOT) that will be built as part of the reconfiguration will be:

- Reduction of vehicle lanes from four to three with the center lane dedicated to turning movements.

- Introduction of bike lanes.
- Reconfiguration and relocation of several intersections (including several pedestrian-only crossings) and adoption of advanced traffic signals.
- Construction of bus turn outs, new streetlights, new pavement and new street furniture.

Thus, this project is a prototype of a 'smart mobility' implementation, involving new technology, multiple modes, and measures to improve bike, pedestrian and vehicle safety. We propose a multi-criterion 'before and after' impact assessment for this reconfiguration project. Major aspects to be assessed include:

- Changes to vehicular volumes, speeds, travel times and vehicle emissions on Forbes Avenue and surrounding streets.
- Changes in public transit ridership
- Changes to bicycle use of Forbes Avenue.
- Air quality impacts (PM2.5, NO_2, CO)

2. Project Description

Forbes Avenue is a major arterial of approximately six miles that connects Pittsburgh's two largest business districts – Oakland (home of Carnegie Mellon, University of Pittsburgh, and a large hospital system) and the central business district. Since the 1960's, the Forbes corridor directly adjacent to Carnegie Mellon consisted of a 4-lane arterial with 2 automotive lanes in each direction. After completion of the complete street project in the summer of 2019, a one-mile section through the heart of Carnegie Mellon's campus (1 mile in length) between Margaret Morrison and Craig Street (see Figure 1) was converted to a 3-lane roadway (with center turn lane) with two bicycle lanes. Project construction began in August of 2018 and concluded in July of 2019. Figure 2 shows before-and-after images of the complete street retrofit facing west toward the University of Pittsburgh campus. Average annual daily traffic in this corridor was 13,000 vehicle per day prior to the retrofit.

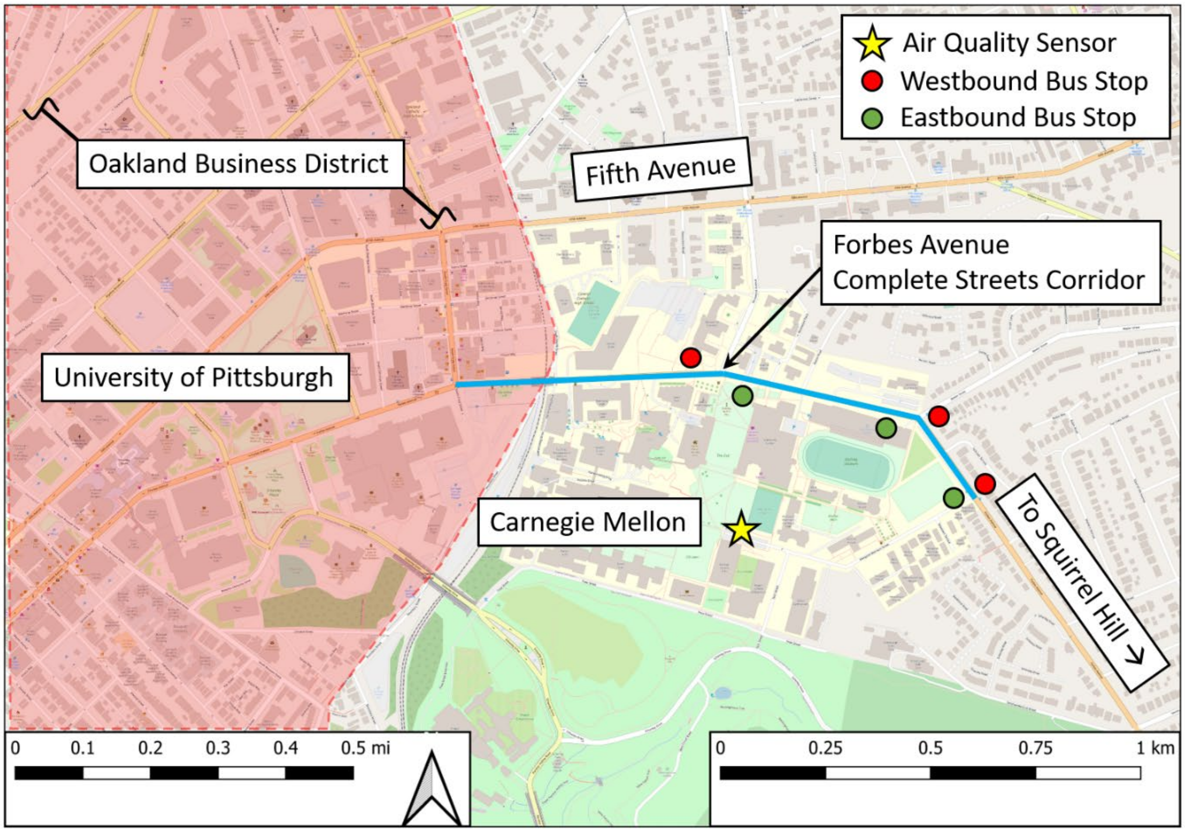

Figure 1 - Complete Street Corridor

Figure 2 - Pre- and post-retrofit images

2. Data & Methods

Multiple sources of data were used to quantify the travel impacts of the complete street retrofit. Through a combination of video, sensor (and vehicle probe), transit ridership data, and accident report data obtained from the Pennsylvania Department of Transportation, before-and-after impacts were quantified for traffic speeds and counts, bicycle counts, air quality, transit ridership, and crash counts. A summary of data sources and uses are provided in Table 1.

Table 1 - Data Summary

Data	Source	Use
Traffic counts	Video camera installed along corridor	Vehicle counts along Forbes Ave.
Traffic speeds	INRIX	Vehicle speeds at Forbes and Fifth
Bicycle counts	Video camera installed along corridor	Bicycle counts along Forbes Ave.
Air quality	Sensors installed at Carnegie Mellon	PM2.5, NO_2, CO concentrations
Public transit ridership	Port Authority of Allegheny County	Bus ridership along Forbes Ave.
Crash counts	Pennsylvania Dept. of Transportation	Crash incidents along Forbes Ave.

For the following analysis, time periods were selected based on data availability to capture travel impacts before, during, and after retrofit completion for each of the metrics presented in Table 1. In all cases, data for representative time periods (days, weeks, or months) were compared before and after construction. All time periods were selected during either fall or spring semesters when both Carnegie Mellon and the University of Pittsburgh were in session. Statistical tests were then used to evaluate the significance of the various travel impacts. The time periods selected to evaluate impacts for each metric are highlighted below in Figure 3.

Vehicle counts:
- Morning Peak [7:30am-7:45am, 8:00am-8:15am, 8:30am-8:45am]
- Evening Peak [4:30pm-4:45pm, 5:00pm-5:15pm, 5:30pm-5:45pm]

Period	Week Selected
Before	April 9-13, 2018
During	October 15-19, 2018
After	October 7-11, 2019

Vehicle speeds:
- Morning Peak [7:30am-9:00am]
- Evening Peak [4:30pm-6:00pm]

Period	Week Selected
Before	September 11-15, 2017
After	September 9-13, 2019

Bicycle counts:
- Morning Peak [8:00am-9:00am, 3 weekdays selected]
- Evening Peak [5:00pm-6:00pm, 3 weekdays selected]

Period	Week Selected
Before	April, 2018
After	September, 2019

Bus ridership:
- Morning Peak [7:00am-10:00am, all weekdays]
- Evening Peak [4:00pm-7:00pm, all weekdays]

Period	Week Selected
Before	Sept-Oct, 2016-2017
During	Sept-Oct, 2018
After	Sept-Oct, 2019

Air Quality:
- All hours

Period	Week Selected
Before	Sept-Oct, 2017
After	Sept-Oct, 2019

Figure 3 - Evaluation time periods

3. Results

3.1 Vehicle Traffic Volume

A camera was installed along Forbes Avenue in March of 2018 to continuously record and store traffic volumes through the end of 2019. Videos were stored in 5-minute increments for all time periods mentioned in Figure 3. Each count was then multiplied by 12 to get a representative hourly traffic count. Morning and evening peak periods were based off peak-periods outlined by the pre-construction engineering study (GAI Consultants 2015). Results for both morning and evening peak periods are plotted in both direction (eastbound and westbound), and are shown in Figure 4 and Figure 5.

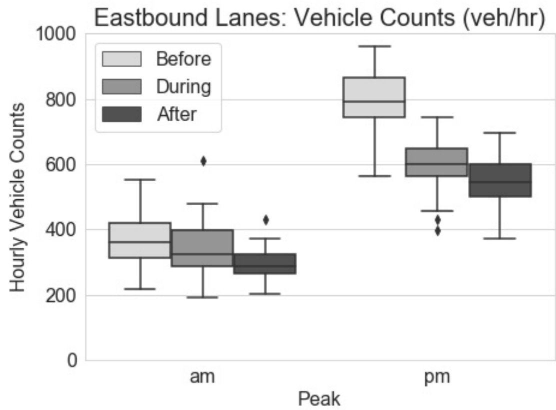

Figure 4 - Eastbound Traffic Volumes

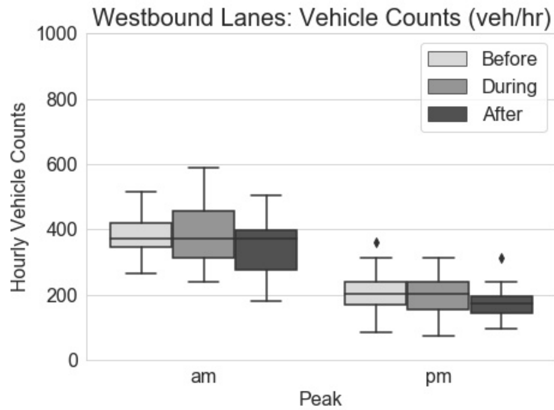

Figure 5 - Westbound Traffic Volumes

Reductions in traffic volumes were observed in all cases after reconfiguration. Traffic volume reductions were significant to the 95% level in all cases using a one-tailed t-test with unequal variances. For cases with lower traffic volumes (eastbound morning peak and both peak periods for westbound traffic), traffic counts were reduced by 11-21%. For the one case with higher initial traffic volumes (eastbound evening peak), traffic counts were reduced by 31%.

3.2 Vehicle Traffic Speed

Traffic speeds were compared using INRIX (2020) data, which uses vehicle probes placed on a variety of vehicles throughout the transportation network. Only real-time traffic speed information along roadways of interest was used to compare before and after impacts. In this analysis, traffic speeds along a parallel corridor (Fifth Avenue) were also compared to evaluate the reconfiguration's impact on diverting traffic.

Table 2 - Mean travel speeds before and after reconfiguration

		Peak	Before (mph)	After (mph)	Difference (mph)	Significance Level
Forbes Avenue	Eastbound	am	16.6	13.7	-2.9	0.01**
		pm	15.7	10.3	-5.4	0.01**
	Westbound	am	13.9	8.8	-5.1	0.01**
		pm	11.7	9.2	-2.5	0.01**
Fifth Avenue	Eastbound	am	17.4	17.3	-0.1	>0.1
		pm	15.6	14.8	-0.8	0.05*
	Westbound	am	8.7	9.4	0.7	0.05*
		pm	12.5	14.9	2.4	0.01**
* Significant at the 95% level, ** Significant at the 99% level						

Travel speeds along Forbes Avenue significantly decreased in all cases. Mean travel speeds were reduced by 2.5-5.4mph, or 15-37%. No clear trend was observed for traffic speed changes along the parallel corridor (Fifth Avenue). Traffic speeds increased in the westbound direction but decreased in the eastbound direction. From this, we conclude that traffic was not adversely affected on Fifth Avenue. The results also indicate that the complete street retrofit was effective in calming traffic along Forbes Avenue.

3.3 Engineering Study Comparison

Prior to construction, a reconfiguration study was conducted by GAI Consultants (2015) to evaluate existing traffic conditions and estimate potential impacts from the retrofit project. Traffic volumes were estimated assuming a 0.25% annual growth rate to inform roadway designs to avoid problematic queues. Estimated projections were then compared with observed changes in traffic volumes to inform future engineering studies. Comparison results are shown in Table 3.

Table 3 - Comparison of traffic volumes (GAI estimated vs observed)

		Eastbound [GAI projections]	Eastbound [observed]	% Difference	Westbound [GAI projections]	Westbound [observed]	% Difference
After	am	357	289	-19%	512	341	-33%
	pm	816	548	-33%	226	174	-23%

Traffic volumes were compared for the after period to assess if the 0.25% annual growth rate was a valid assumption when making predictions for similar complete street projects. The GAI projected traffic volumes were 19-33% higher compared to observed traffic volumes after project completion. This result indicates that the 0.25% growth rate might be conservative for similar complete street projects.

3.4 Bicycle Counts

A common goal for complete street projects is to improve safety and access for active modes of transit. One common design component of most complete street projects is the addition of bike lanes to dedicate space and improve safety for cycling modes. In this analysis, time periods are selected (see Figure 3) to capture days with similar weather conditions. Full one-hour videos were used to count bicycles in both directions because cyclists are rare and using 5-minute video segments might not capture the true changes in bicycle traffic. Additionally, precipitation was not observed for the time periods selected. Total bicycle traffic for morning and evening peaks is plotted in Figure 6.

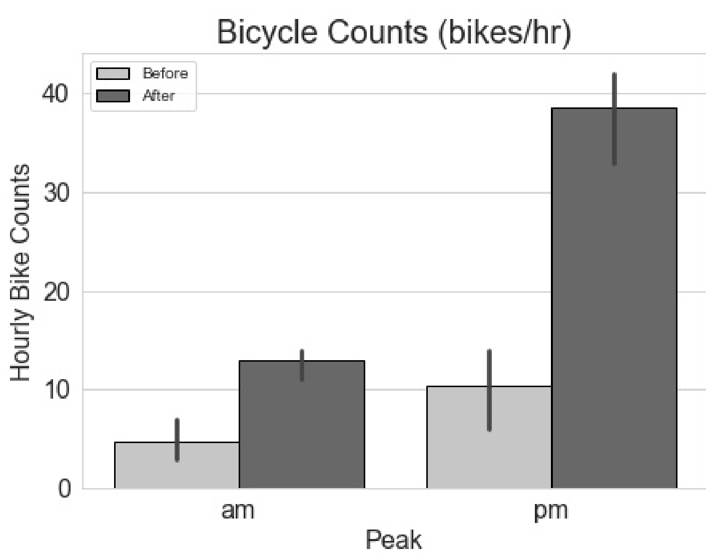

Figure 6 - Before and after bicycle counts

Average hourly bicycle counts increased by 160% and 280% in the morning and evening peaks, respectively. The location of the corridor likely influences the large increases in bicycle traffic because it serves as a connector between residential neighborhoods and the Oakland business district. The large increase in bicycle traffic indicates that bicycle commuters feel safe using the complete street corridor, which also aligns with anecdotal evidence of increased bike lane users.

3.5 Public Transit Ridership

Stop-level bus ridership data from 2016-2019 was obtained to evaluate changes in onboardings and alightings within the complete street corridor before and after the retrofit. Only stops located within the corridor were analyzed to investigate potential mode shift for travelers departing or arriving at locations near the complete street corridor. Because most of the corridor sits adjacent to Carnegie Mellon, trip generation during the morning hours was low. Due to this, egress counts were analyzed for morning peak hours and boardings were analyzed for evening peak hours. Student enrollment growth was constant at 1% between 2016-2019, so it is not expected that changes in bus ridership are due to increased student populations. It is important to not that both universities (Carnegie Mellon and the University of Pittsburgh) provide prepaid bus cards to all students, faculty, and staff, however, this system was present pre-2016. Figure 7 plots total peak-period bus ridership for both morning and evening peaks for the years mentioned.

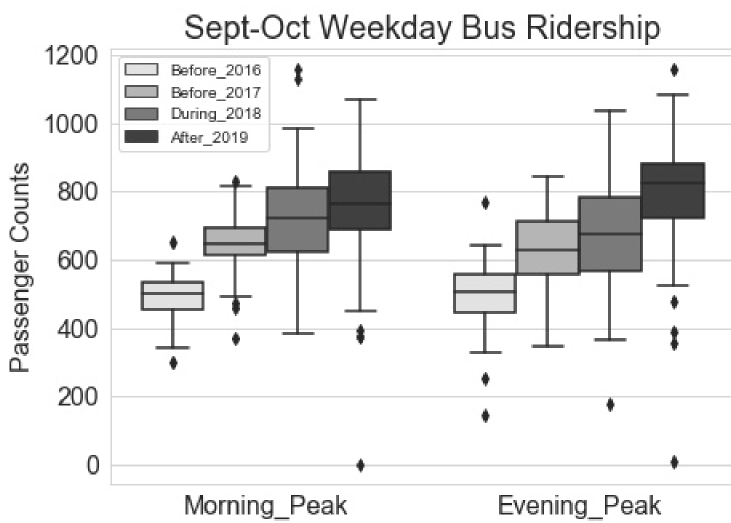

Figure 7 - Before and after bus ridership

By observation, bus ridership trends have been steadily increasing since 2016. While increased ridership is observed for the post-retrofit period, it is difficult to attribute ridership gains to the retrofit alone. Access to bus stops along the corridor did not change, so only small changes in ridership were expected. It will be important to continue to monitor bus ridership along the corridor in the future as Carnegie Mellon continues to develop north of Forbes Avenue.

3.6 Air Quality

On campus air quality sensors installed by Carnegie Mellon's Center for Atmospheric Particle Studies were used to quantify before and after air quality impacts near the corridor project. Sensors were located 900-ft away from the corridor, making it difficult to capture on-roadway ultrafine particulates, however, PM2.5, NO_2, and CO concentrations were analyzed to evaluate local trends. Air quality sensors stored measurements at 15-minute increments, and the full months of September and October were used to compare before-and-after impacts. Figure 8 plots average daily PM2.5 concentrations for each period. Figure 9 plots average hourly PM2.5 concentrations with 95% confidence intervals.

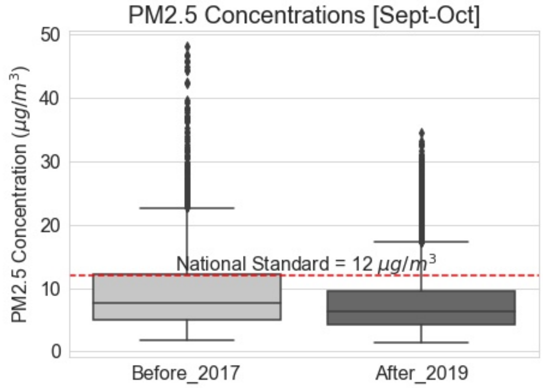

Figure 8 - Average PM2.5 Concentrations

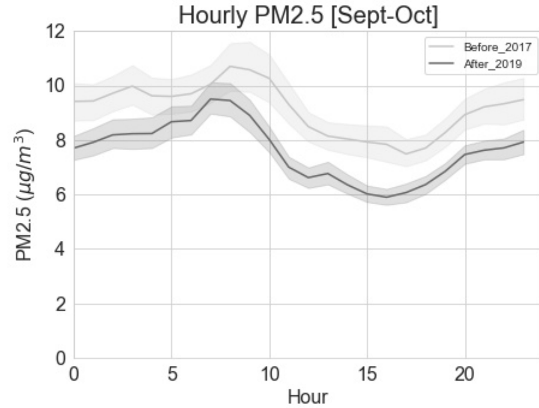

Figure 9 - Hourly PM2.5 Concentrations

The mean PM2.5 concentration decreased from 9.1µg/m^3 to 7.6µg/m^3 after the completion, which are both well below the national standard set by the EPA of 12µg/m^3. The hourly plots with 95% confidence intervals show the daily fluctuations of PM2.5 concentrations. Because clearly defined peaks are not observed during morning and evening peaks, other factors must be influencing concentrations along the corridor, such as greater mixing during times of day when air temperatures are higher.

NO_2 and CO concentrations were also evaluated because they are also fossil fuel byproducts. The mean NO_2 concentrations increased from 7.5ppb to 8.4ppb and the CO concentrations decreased from 267ppb to 245ppb after the reconfiguration. However, in both cases, concentrations were well below standards set by the EPA (100ppb and 35,000ppb, respectively). Average daily before and after concentrations are plotted in Figure 10 and Figure 11.

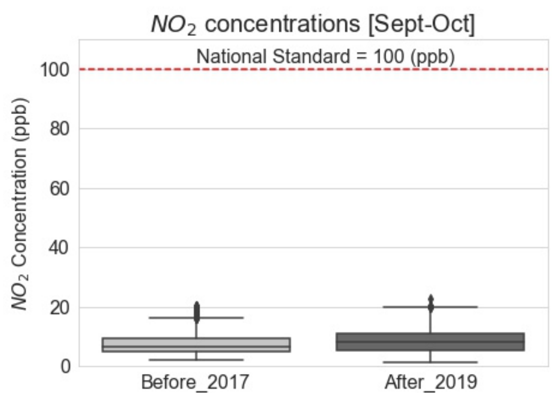

Figure 10 - Average Daily NO_2 Concentrations

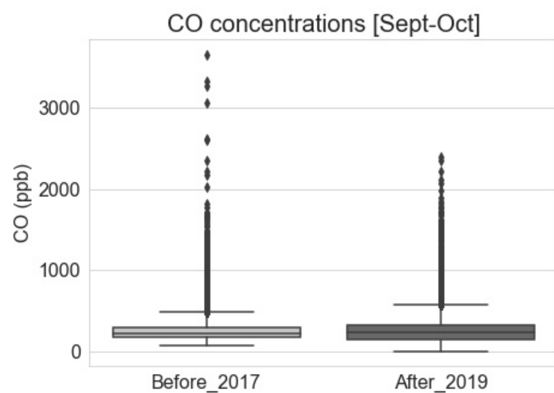

Figure 11 - Average Daily CO Concentrations

3.7 Crash Counts

Crash data (all incidents involving a motor vehicle) was obtained from the Pennsylvania Department of Transportation for all years between 2010-2019. Only incidents within the complete street corridor are plotted in Figure 12. A continuous downward trend is observed, however, concrete conclusions are difficult to make without monitoring crash frequency for additional years. It is important to note that no incidents were reported after completion (July 2019). All observed incidents in 2019 occurred before the completion of the retrofit project. Because traffic speeds and volumes both decreased after the retrofit and pedestrian crosswalks and bike lanes were added, an increase in crashes in subsequent years is not expected.

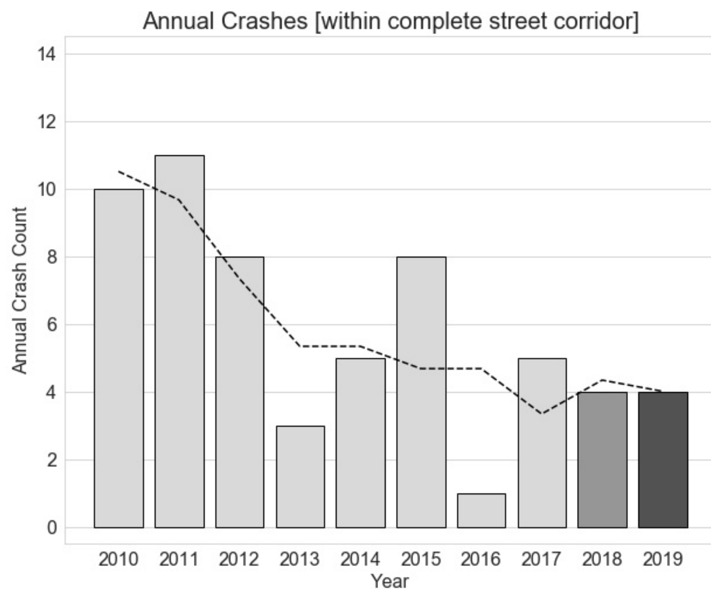

Figure 12 - Annual crash counts along corridor

4. Discussion

Multiple sources of data were collected and analyzed to provide a more holistic picture about travel impacts before and after a complete street retrofit. Reductions in traffic volumes and speeds were observed, which indicates that the project was effective in calming traffic through the corridor. Additionally, no adverse effects were observed on parallel corridors. Bicycle volumes increased drastically (160% and 280% for morning and evening peaks, respectively) after completion of the retrofit, indicating that bicycle commuters feel safer within the corridor. Public transit ridership also increased after retrofit, however, it is difficult to attribute all the gains in ridership to the retrofit alone. When looking at the results together, there seems to be evidence of some mode shift among travelers due to reduced vehicle traffic and increased bicycle and transit volumes and likely no additional vehicular traffic along parallel corridors due to small changes in vehicle speeds. These results are consistent with the study along Telegraph Avenue in Oakland, CA (Fine and Tapase 2017).

PM2.5 concentrations decreased from 9.1µg/m^3 to 7.6µg/m^3 after retrofit, however, both concentration levels are well below the EPA standard of 12µg/m^3. Similar results were observed for NO_2 and CO concentrations, in that small changes were observed, but average daily concentrations were both well below EPA standards. Because the sensors were displaced 900-ft from the roadway, ultrafine particulate matter concentrations were not collected. However, due to their impacts on human health, new sensors should be placed closer to the corridor in future work to monitor these changes in addition to the measurements collected in this study.

Finally, crash frequency did not increase during construction, indicating that the construction phase of the project did not adversely affect traffic safety. While similar crash rates were observed during both "during" and "after" phases of the project, no accidents were observed in the months directly following complete street completion (Aug – Dec 2019). Long-term safety impacts were not evaluated, however, with the addition of pedestrian crossings and dedicated bike lanes and the observation that both traffic speeds and volumes decreased after project completion, a future increase in crash frequencies is not expected.

Additional information regarding the current literature, project description, project costs, and more in-depth discussion of the methods and results can be viewed in the journal publication listed in Appendix A.

Appendix A

A.1 Journal Publications

Grahn, R., Hendrickson, C., Matthews, H.S., Qian, S., Harper, C.D. (2020) "Societal impacts of a complete street project in a mixed urban corridor: A case study in Pittsburgh, PA" *Journal of Infrastructure Systems: ASCE.*

A.2 Datasets

Air quality dataset available at https://github.com/rgrahn/Forbes-Reconfiguration-Project.
Vehicle crash dataset available at https://data.wprdc.org/dataset/allegheny-county-crash-data.
Bus ridership and traffic videos exceed maximum files sizes for Github but can be made available upon request.

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