A USDOT NATIONAL UNIVERSITY TRANSPORTATION CENTER

Traffic Impact Study of CSX Pittsburgh Intermodal Rail Terminal and Mitigation Plans for McKees Rocks

Final Research Report

Submitted to Smart Mobility Challenge with the Borough of McKees Rocks

PI: Sean Qian

Graduate Student Researchers: Xidong Pi, Wei Ma

Mobility Data Analytics Center (MAC)
Carnegie Mellon University

Contract # 69A3551747111

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1. Introduction

1.1 Project Background

A CSX intermodal rail terminal is planned to open in late 2017 on a parcel of land located immediately north of the McKees Rocks Bridge in the Borough of McKees Rocks and Stowe Township, PA. The development will consist of an intermodal facility that will accommodate approximately 50,000 lifts per year opening year (2018) and 136,000 lifts per year at full buildout (2023). Access to the terminal is proposed via a new Angelina Avenue to Island Avenue (SR 0051). It is expected to generate a significant number of trucks in the Borough of McKees Rocks, which adds additional burdens on the existing roadway in the Borough. A map showing the locations of McKees Rocks and the new railway terminal is in Figure 1. The terminal may bring in heavy congestion to individual roadway drivers. A traffic impact study was conducted indicating a minor congestion increase with the new infrastructure.

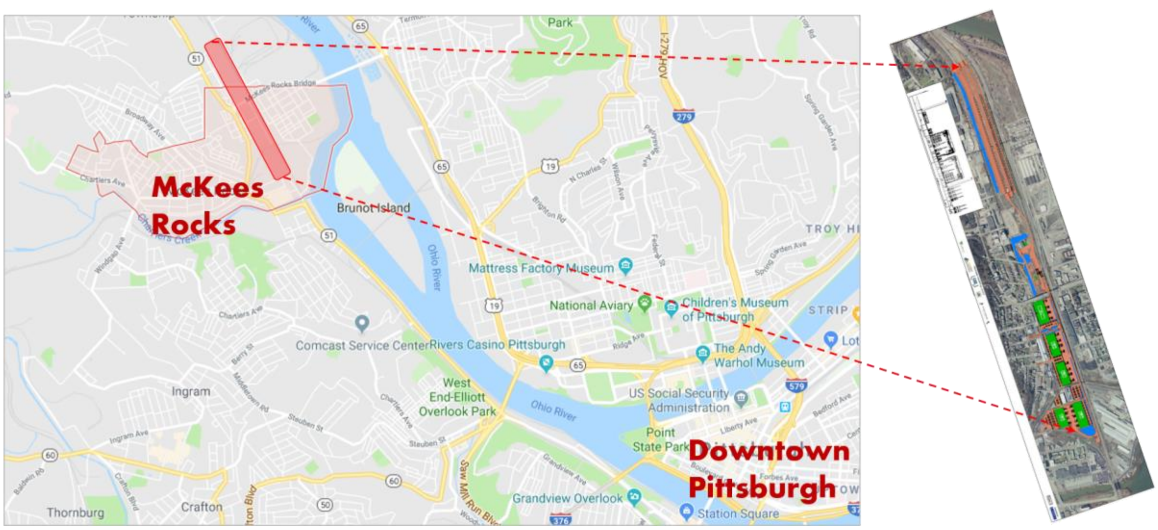


Figure 1 McKees Rocks locates in the northwest of downtown Pittsburgh. The red rectangle represents the development site.

This research project conducts an in-depth analysis of the potential traffic impact in high temporal and spatial resolutions. Using the data collected in the traffic impact study along with other relevant data sets possessed by CMU Mobility Data Analytics Center, we simulate individual cars and trucks, and model their route choices, travel time and mixed traffic flow conditions. The result includes the travel time, travel delay, vehicle-mile-traveled and emissions for each road segment and intersection by time of day. We will also examine the effectiveness of potential traffic management strategies, specifically West Carson Street Extension and truck routing.

1.2 Tasks

For conducting an in-depth analysis of the potential traffic impact of the new CSX intermodal railway terminal in high temporal and spatial resolutions, we have the following main tasks:

1. **Task 1:** Identify various data sources for in-depth data analytics including:
    a. The first data is a GIS model for the Greater Pittsburgh area. We also need to establish a refined GIS model for McKees Rocks district and its surrounding areas. A stand-alone version of Borough/Township GIS with the following data is necessary for this study, which should include street names, street levels (highway, major arterials, minor streets, alleys, etc.), the number of lanes, and speed limit.
    b. Obtain historical traffic volume count data for main road segments from PennDOT.
    c. Obtain historical travel time data for main road segments from INRIX.
    d. Obtain the number of cars and trucks to be generated by the new rail terminal.
2. **Task 2:** Modeling of the existing traffic conditions without the terminal. We will use a mesoscopic network analysis methodology to conduct this research. CMU Mobility Data Analytics Center uses a dynamic network analysis tool (MAC-POSTS) which is capable of estimating network-wide traffic impact for any general networks consisting of freeway, arterials and local streets. It has the capacity of modeling dynamic traffic evolution for both trucks and cars, with the consideration of travel control and demand management. It adopts state-of-the-art traffic models and is much more computationally efficient than other microscopic models that are extremely labor intensive to build. We first model the existing traffic conditions using MAC-POSTS. The estimated travel time and flow rates are expected to match those observations collected in the Task 1.
3. **Task 3:** Modeling of the future traffic conditions with the presence of the terminal. In this task, we extend and apply the model calibrated in Task 2 to forecast the future traffic conditions. We first add the new roadway that are planned as the CSX facility becomes operational. We then load the additional cars and trucks generated by the terminal to the network model. The traffic impact can be measured by time-of-day performance metrics at both the street level and the regional level, such as total traffic delay, average travel time, emissions, energy use, vehicle-miles traveled, etc.
4. **Task 4:** Modeling the potential benefits of traffic mitigation plans. In addition, we examine the effectiveness of several potential traffic management strategies.

For example, West Carson Street may be expanded to mitigate traffic impacts. We will work with the Borough managers and engineers to identify extension plans and encode them into the MAC-POSTS model established in Tasks 2 and 3. We can run the model and compare the results to those obtained in Task 3. Another example is we will examine truck routing plans that include time-of-day truck access restrictions and truck routing advisory information. Again the results will be obtained by the MAC-POSTS and compared to the results obtained in Task 3.

2. Data Collection and Pre-processing

2.1 GIS model

The GIS model used in this study is the Southwestern Pennsylvania Network provided by the Southwestern Pennsylvania Commission (SPC), which covers the southwestern Pennsylvania ten counties, with the Pittsburgh city in the central area, see Figure 2. This network model contains 16,110 road segments, 6,297 intersections, 283 origin and 283 destination zones. The GIS model is used to encapsulate the ripple effects of CSX terminals in the large-scale regional network.

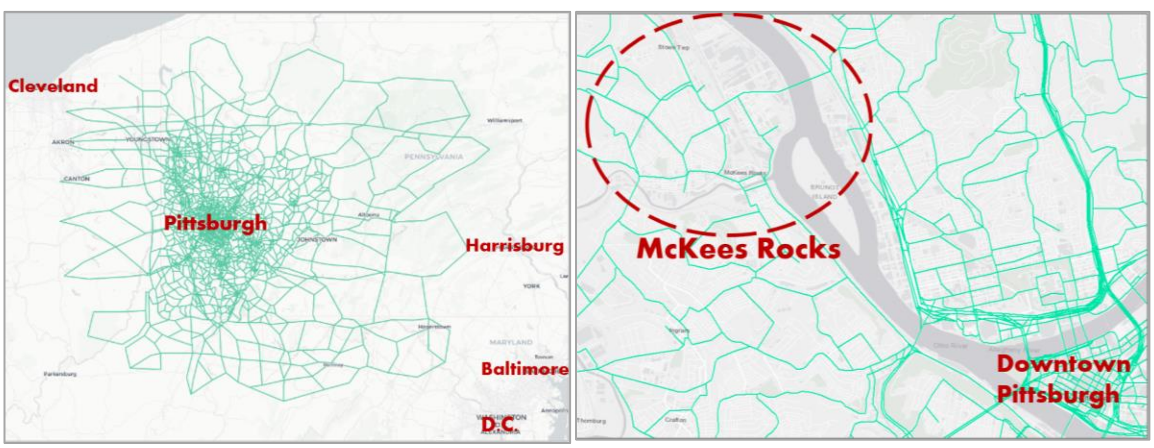


Figure 2 The Southwestern Pennsylvania GIS model. Left: whole coverage. Right: McKees Rocks district and downtown Pittsburgh.

For McKees Rocks district and its surrounding areas, we refined the GIS model by calibrating the street and intersection latitude and longitude, the street levels (highway, major arterials, minor streets, alleys, etc.), the number of lanes, street segment length, and speed limit.

Figure 3 shows the streets and intersections that are fully examined for impacts in detail. These streets are:

- McKees Rocks Bridge (SR 3104)
- Angelina Avenue
- Island Avenue (SR 0051)
- Chartiers Avenue
- Stanhope Street

The intersections examined in detail are:

- Helen Street and McKees Rocks Bridge
- Island Avenue and McKees Rocks Bridge
- Angelina Avenue and Island Avenue
- Island Avenue and Chartiers Avenue
- Chartiers Avenue and Stanhope Street

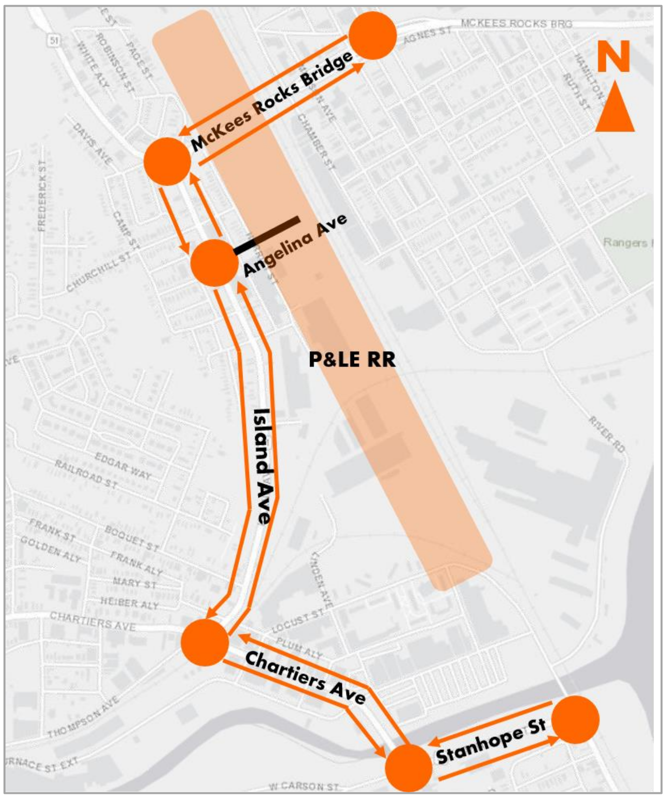


Figure 3 The streets and intersections studied in this project.

2.2 Traffic counts and speed data

Before we analyze the impact, we need to calibrate our simulation model with historical traffic volume counts and speed measurements. In this project we used Pennsylvania Department of Transportation (PennDOT) hourly counts data and Federal Highway Administration (FHWA) travel time data for year 2016 to do the calibration. A direct map visualization of these two datasets are shown in Figure 4.

Traffic volume count **Traffic speed**

Figure 4 Traffic volume count and traffic speed data we used for the Greater Pittsburgh area.

The PennDOT hourly count data contains hourly traffic volume count for one day at some selected locations on state routes in Pennsylvania. The count data are classified to car count and truck count, where car count is the total traffic volume of all passenger cars at the location and truck count is the total traffic volume of all kinds of trucks at the location. All counts are measured in hours, so each one-hour count is divided and smoothed to 15-minute interval traffic count for calibrating the dynamic OD demand matrix. In total, there are 608 locations with valid car and truck volume counts.

Speed measurements are from FHWA 5-minute travel time data for year 2016. The speed data are collected for highway segments and are also classified to passenger car speed and freight truck speed, which are measured for every 5-minutes of the day. These speed measurements are averaged for different days in 2016 and also aggregated to 15-minute interval speed measurements for next step model calibration. In total, there are 945 locations with valid car and truck speed measurements.

2.3 Trip generation data

Trip generation estimation data for the new CSX intermodal railway terminal is obtained from a previous traffic impact study conducted in 2014 by Gannett Fleming. In their trip generation estimation, the new demand for car and truck trips are estimated for in and out trips and for AM Peak hour and PM Peak hour separately. The details of trip generation are concluded in Table 1.

CSX Pittsburgh Intermodal Rail Terminal
Trip Generation Estimates

Opening Year (2016) Trip Generation Estimates

Development Component	AM Peak Hour			PM Peak Hour		
	In	Out	Total	In	Out	Total
Truck Traffic	17	17	34	12	11	23

Full Buildout Year (2023) Trip Generation Estimates

Development Component	AM Peak Hour			PM Peak Hour		
	In	Out	Total	In	Out	Total
Truck Traffic	32	32	64	21	21	42
Employees	19	0	19	0	0	0
Total	**51**	**32**	**83**	**21**	**21**	**42**

Trinity Manufacturing/Warehouse Development
Trip Generation Estimates

Phase I Trip Generation Estimates

Development Component	AM Peak Hour			PM Peak Hour		
	In	Out	Total	In	Out	Total
121,500 sf Manufacturing	55	16	71	28	51	79
162,000 sf Warehouse	85	23	108	20	61	81
Total	**140**	**39**	**179**	**48**	**112**	**160**

Phase II Trip Generation Estimates

Development Component	AM Peak Hour			PM Peak Hour		
	In	Out	Total	In	Out	Total
220,000 sf Warehouse	100	27	127	25	74	99

Table 1 Trip generation data from the report of "Transportation Impact Study Proposed CSX Pittsburgh Intermodal Terminal, Borough of McKees Rocks and Stowe Township, PA"

3. Modeling the Existing Traffic Conditions without the Terminal

For modeling the existing traffic conditions without the terminal, we use a mesoscopic network analysis methodology to conduct this research. CMU Mobility Data Analytics Center uses a dynamic network analysis tool (MAC-POSTS) which is capable of estimating network-wide traffic impact for any general networks consisting of freeway, arterials and local streets. It has the capacity of modeling dynamic traffic evolution for both trucks and cars, with the consideration of travel control and demand management. It adopts state-of-the-art traffic models and is much more computationally efficient than other microscopic models that are extremely labor intensive to build. We first calibrate the model parameters using historical traffic volume count data and traffic speed data, as introduced in Section 2.2. Then the model is used to generate the existing traffic conditions including travel time, delays, VMT, fuel consumptions, and other emission metrics for the baseline year 2016.

3.1 Model calibration

We do the calibration by tuning the traffic demand among different origins and destinations and other network parameters. After calibration, the traffic conditions generated by the simulation model should match the sensor measurement well. Figure 5 shows the traffic volume count match between simulated count from simulation model and measured count from PennDOT traffic count dataset for McKees Rocks Bridge eastbound and westbound. It shows locally our simulation model can generate the traffic conditions in baseline year 2016.

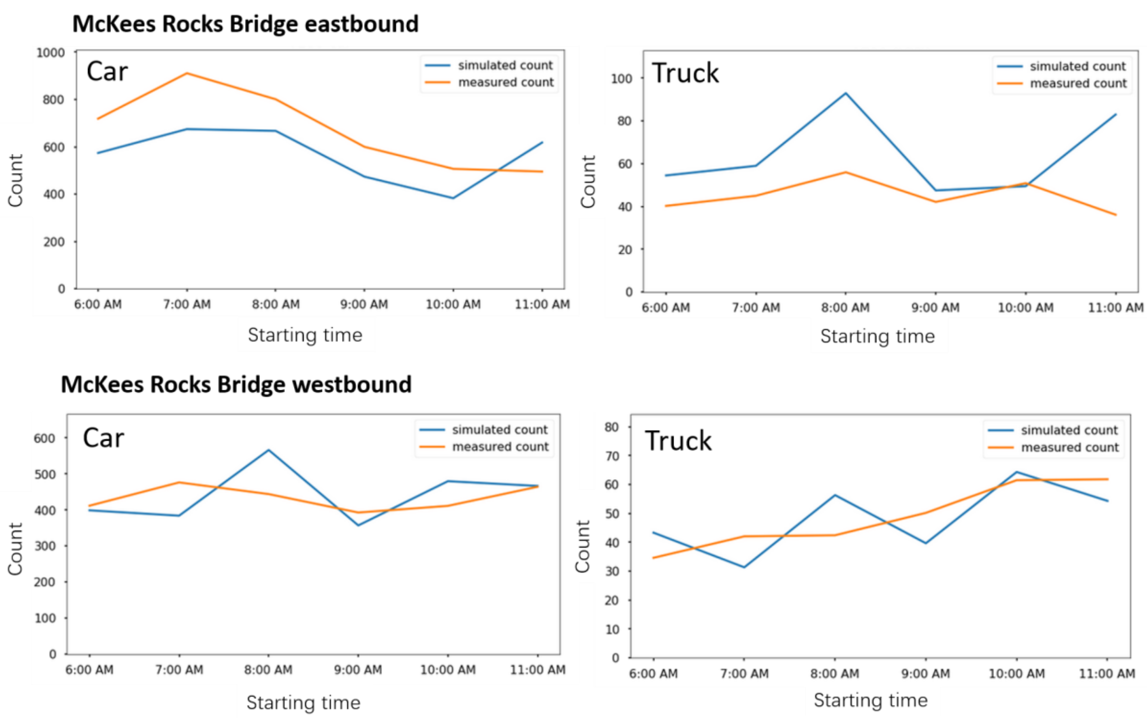
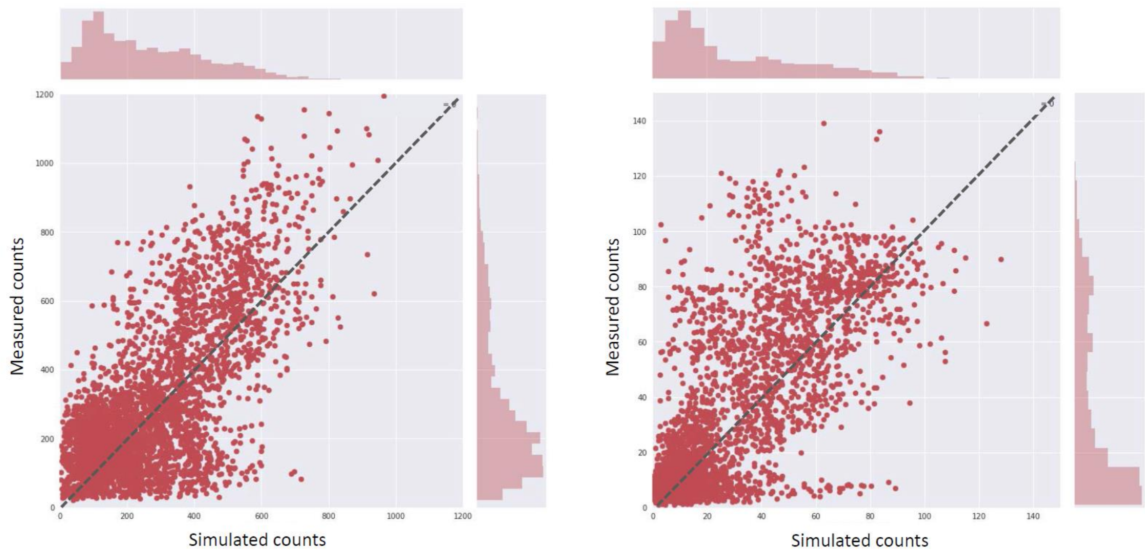


Figure 5 Traffic volume count match between simulated count and measured count.

For the whole the Southwestern Pennsylvania Network, the counts match between measured counts and simulated counts is shown in Figure 6, for car counts and truck counts separately. For car count the R^2 score is 0.50 and for truck it is 0.52. It shows our simulation model can generate the real traffic states in a good level for the whole traffic network.



Car Count (R^2= 0.50)   Truck Count (R^2= 0.52)

Figure 6 Traffic volume count match between simulated count and measured count for the whole Southwestern Pennsylvania Network.

3.2 General Metrics of existing traffic conditions

After calibration, the model is used to generate the existing traffic conditions including travel time, delays, VMT, fuel consumptions, and other emission metrics for the baseline year 2016. The results for AM peak hours (6:00 AM – 12:00 PM) and PM peak hours (2:00 PM – 8:00 PM) are summarized in Table 2.

Baseline year (2016)

AM PEAK

	Total travels	Total travel time (hour)	Average travel time (min)	VMT (mile)	Fuel (gallon)	CO_2 (kg)	CO (kg)	HC (kg)	NOX (kg)
Car	17610	361.74	1.23	9703.29	331.10	2943.04	11.14	7.85	10.54
Truck	1837	46.12	1.51	855.82	29.27	260.17	2.22	1.02	3.79

PM PEAK

	Total travels	Total travel time (hour)	Average travel time (min)	VMT (mile)	Fuel (gallon)	CO_2 (kg)	CO (kg)	HC (kg)	NOX (kg)
Car	18873	595.56	1.89	10266.32	372.83	3313.37	11.90	9.65	11.54
Truck	1113	40.23	2.17	568.12	19.61	174.28	1.44	0.70	2.54

Table 2 General metrics of traffic conditions for baseline year 2016.

3.3 Road and intersection-based travel time and delays

The travel time between any intersections, the delays at any intersections, the congestion level of any street segments, and the travel time to any important locations outside the community can be computed for the baseline year 2016. Figure 7 and Figure 8 are the average travel time between intersections for AM peak hour and PM peak hour, respectively. Figure 9 is the average delay per vehicle at intersections. Figure 10 shows the probability of heavy congestion on the link that vehicles queue up to upstream links during peak hours. Figure 11 shows the peak hour average travel times to key travel locations outside of the community, including downtown Pittsburgh, the Pittsburgh international airport and I-76 & I-79 interchange.

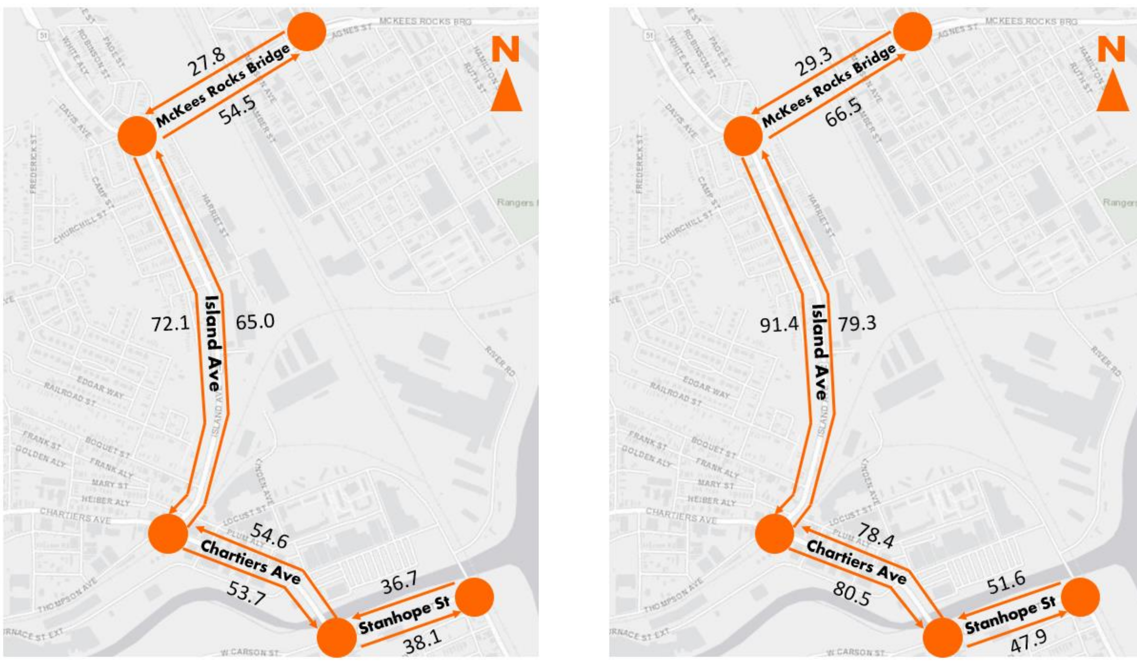


Figure 7 Year 2016 AM Peak hour average travel time between intersections (unit: second)

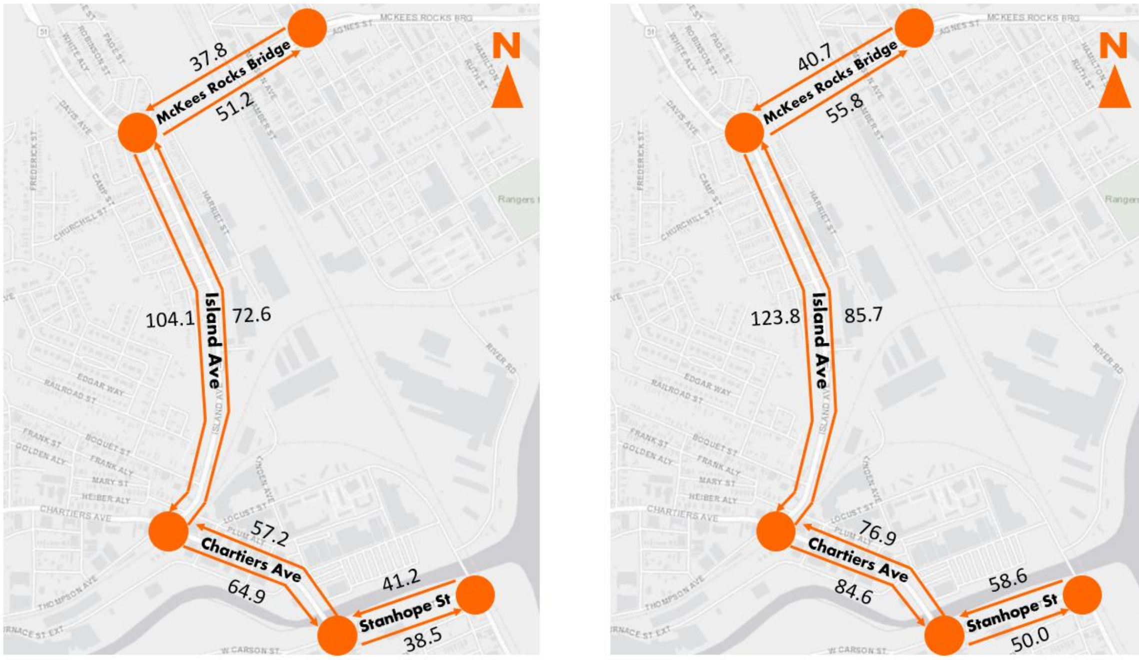


Figure 8 Year 2016 PM Peak hour average travel time between intersections (unit: second)

Figure 9 Year 2016 Average delay per vehicle at intersections (unit: second)

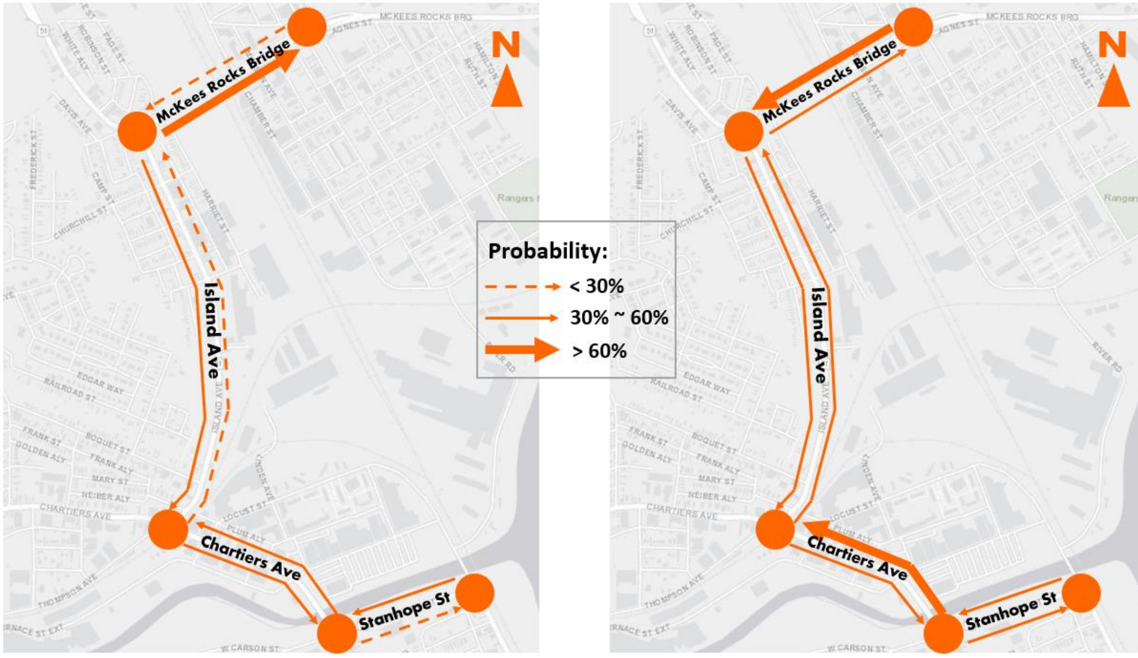


Figure 10 Year 2016 Probability of heavy congestion on the link that vehicles queue up to upstream links during peak hours

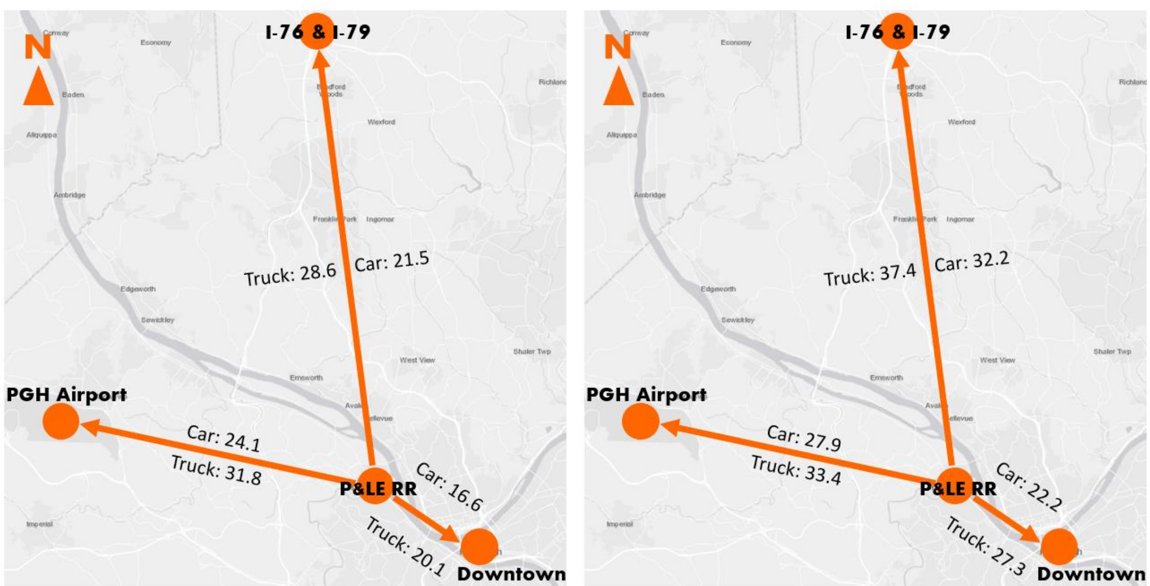


Figure 11 Year 2016 Peak hour average travel times to key travel locations outside of the community (unit: minute)

4. Modeling the Future Traffic Conditions with the Presence of the Terminal

We extend and apply the model calibrated in Section 3.1 to forecast the future traffic conditions. We first add the new roadway that are planned as the CSX facility becomes operational. We then load the additional cars and trucks generated by the terminal to the network model. The traffic impact can be measured by time-of-day performance metrics at both the street level and the regional level, such as total traffic delay, average travel time, emissions, energy use, vehicle-miles traveled, etc.

4.1 General metrics of future traffic conditions

If we assume no traffic management or control scheme and no population and industrial/freight traffic growth from year 2016, then the traffic conditions including travel time, delays, VMT, fuel consumptions, and other emission metrics for full buildout year 2023, as well as the percentage change from year 2016 are summarized in Table 3.

Full buildout year (2023)

AM PEAK

	Total travels	Total travel time (hour)	Average travel time (min)	VMT (mile)	Fuel (gallon)	CO_2 (kg)	CO (kg)	HC (kg)	NOX (kg)
Car	17629	420.34	1.43	10123.14	350.10	3111.57	11.74	8.41	11.13
Change (%)	+0.11	+16.20	+16.26	+4.33	+5.74	+5.73	+5.39	+7.13	+5.60
Truck	2207	62.03	1.69	1048.01	38.03	327.36	2.86	1.25	4.76
Change (%)	+20.14	+34.49	+11.92	+22.46	+29.96	+25.83	+28.83	+22.94	+25.67

PM PEAK

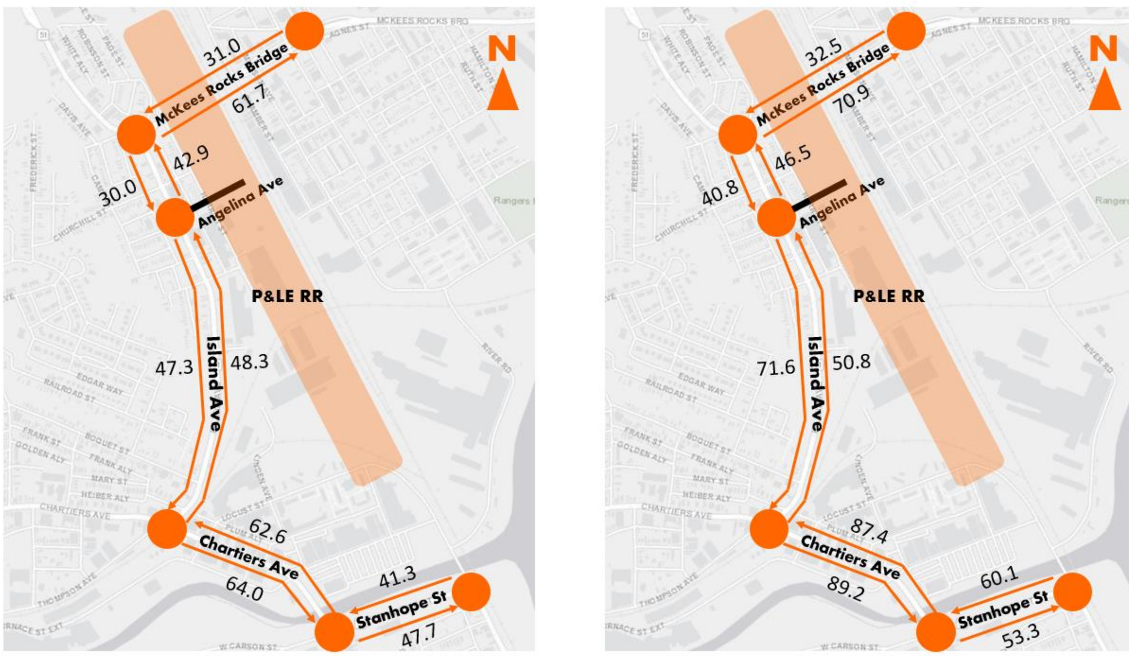
	Total travels	Total travel time (hour)	Average travel time (min)	VMT (mile)	Fuel (gallon)	CO_2 (kg)	CO (kg)	HC (kg)	NOX (kg)
Car	18873	718.90	2.29	10608.09	417.50	3710.34	13.64	10.39	13.10
Change (%)	0	+20.71	+21.16	+3.33	+11.98	+11.98	+14.62	+7.67	+13.52
Truck	1438	60.82	2.54	737.04	25.71	228.55	1.88	0.89	3.32
Change (%)	+29.20	+51.19	+17.05	+29.73	+31.14	+31.14	+30.83	+28.14	+30.87

Table 3 General metrics of traffic conditions for full buildout year 2023 and percentage change from baseline year 2016.

The results show the percentage change is large for the full buildout year 2023 from the baseline year, which means the impact of the new railway terminal to local traffic is significant. Especially for the PM peak hours, the impact is larger.

4.2 Road and intersection-based travel time and delays

The travel time between any intersections, the delays at any intersections, the congestion level of any street segments, and the travel time to any important locations outside the community can also be estimated for the full buildout year 2023. Figure 12 and Figure 13 are the average travel time between intersections for AM peak hour and PM peak hour, respectively. Figure 14 is the average delay per vehicle at intersections. Figure 15 shows the probability of heavy congestion on the link that vehicles queue up to upstream links during peak hours. Figure 16 shows the peak hour average travel times to key travel locations outside of the community, including downtown Pittsburgh, the Pittsburgh international airport and I-76 & I-79 interchange.



Car Truck

Figure 12 Year 2023 AM Peak hour average travel time between intersections (unit: second)

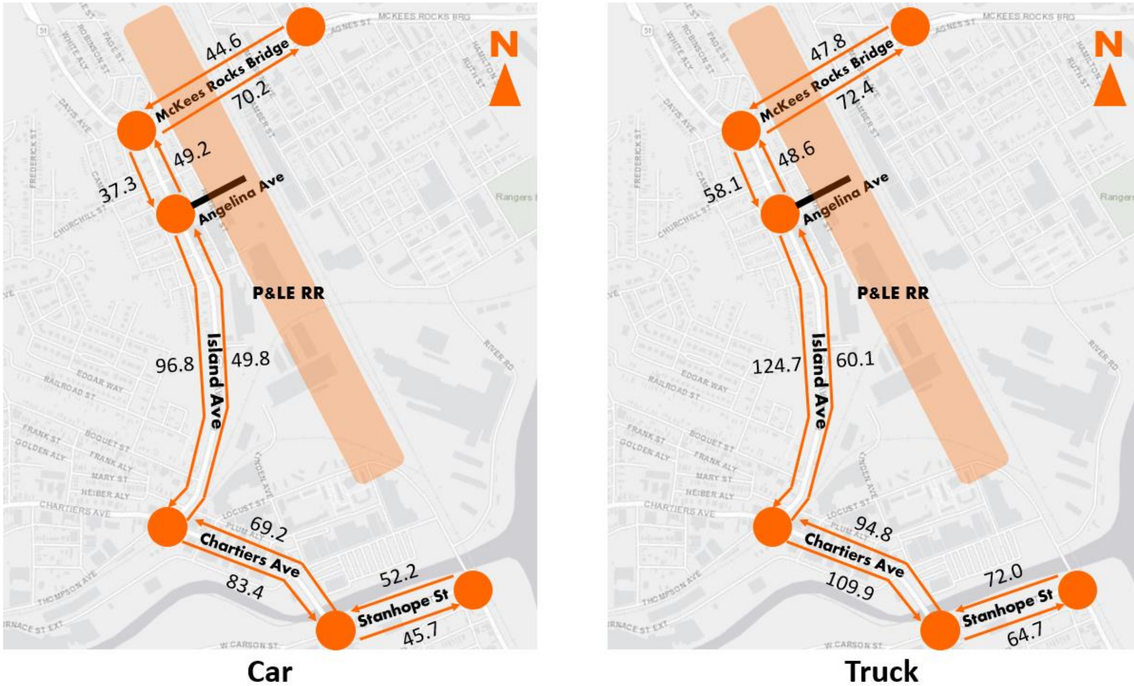


Figure 13 Year 2023 PM Peak hour average travel time between intersections (unit: second)

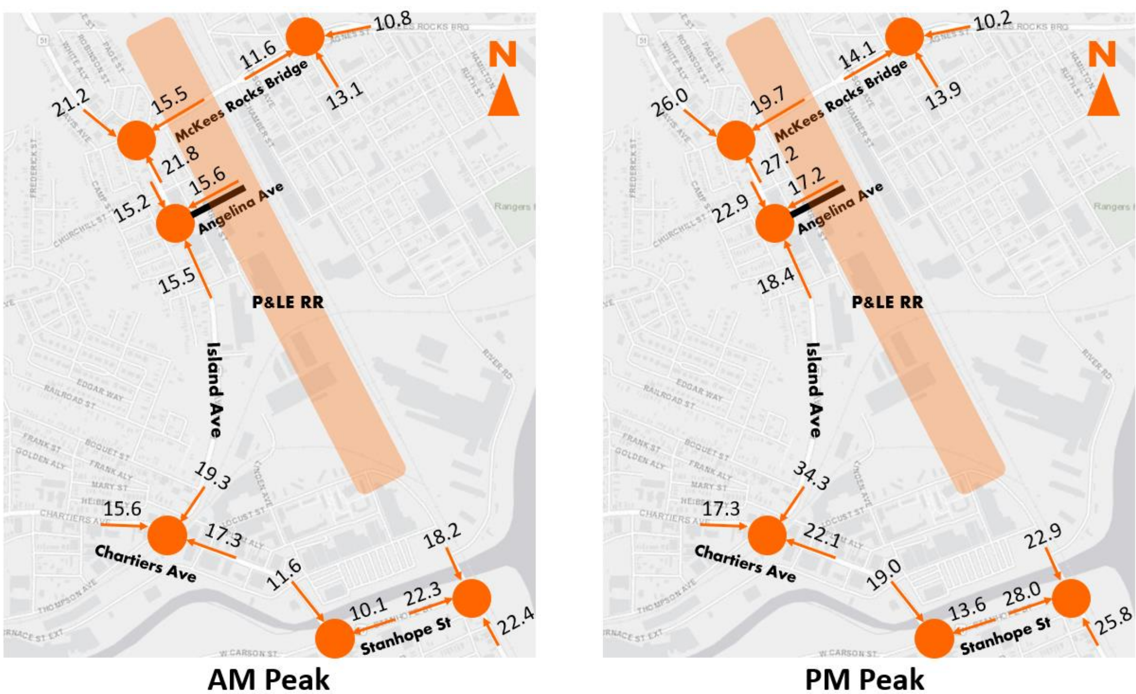


Figure 14 Year 2023 Average delay per vehicle at intersections (unit: second)

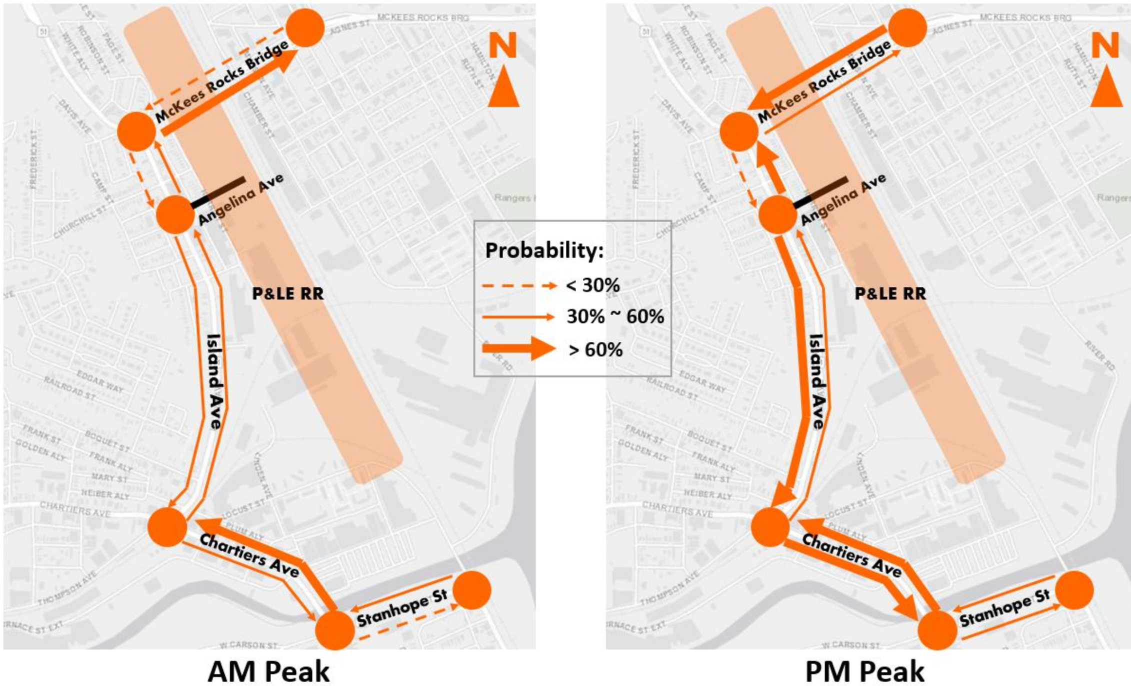


Figure 15 Year 2023 Probability of heavy congestion on the link that vehicles queue up to upstream links during peak hours

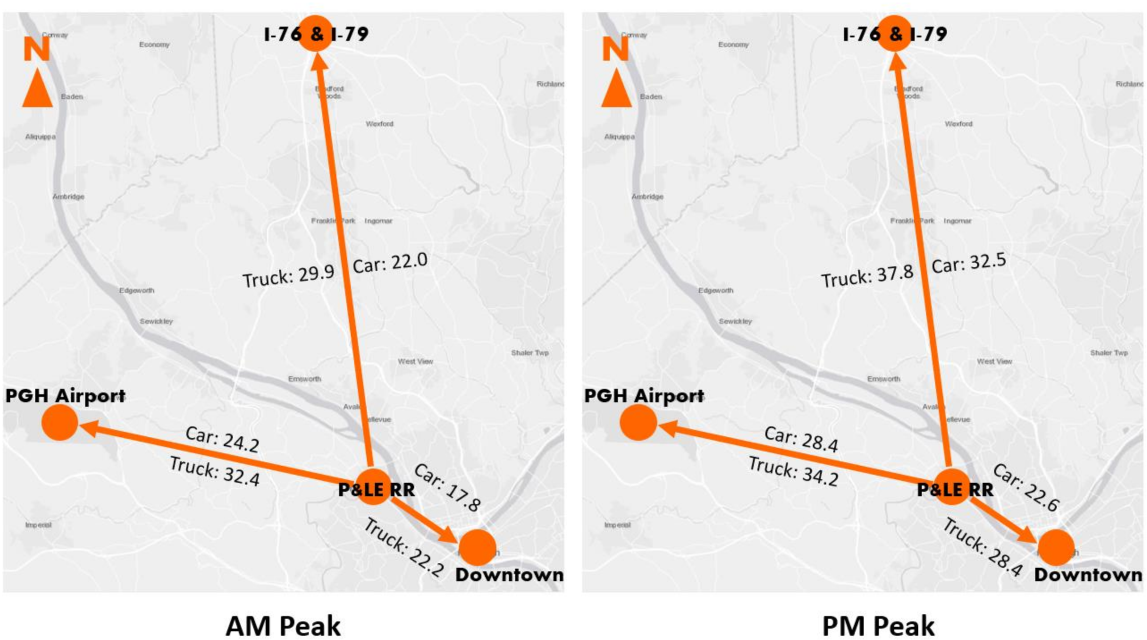


Figure 16 Year 2023 Peak hour average travel times to key travel locations outside of the community (unit: minute)

5. Modeling the Potential Benefits of Traffic Mitigation Plans

To find a useful traffic management and control strategy that alleviates the traffic impact of the new rail terminal and warehouses. There are usually three directions for alleviating traffic congestion: 1) reduce the total traffic demand, for example reduce the scale of the new railway terminal. 2) increase the total traffic network supply, for example build new roadways or extend existing roadways. 3) apply proper traffic control strategies to allocate the traffic demand more reasonably in the network temporally and spatially, for example applying turning restrictions, ramp metering, adding reversible lanes, limit peak hours truck traffic, etc.

5.1 Description of Scenarios

In this project, we mainly test the following scenarios, with either different traffic mitigation plans or traffic demand changes, including:

1. Scenario 0: full buildout year 2023 without any traffic mitigation strategies.
2. Scenario 1: A West Carson Street Extension gets built into the P&LE RR site and is designated "truck only", successfully diverting 85% of trucks that do not have a McKees Rocks destination off of Chartiers Avenue and Island Avenue between Stanhope Street and Angelina Avenue.
3. Scenario 2: A West Carson Street Extension gets built into the P&LE RR site that is used by all vehicle types and it diverts 85% of trucks and 50% of personal vehicle that do not have a McKees Rocks destination off of Chartiers Avenue and Island Avenue between Stanhope and Angelina.

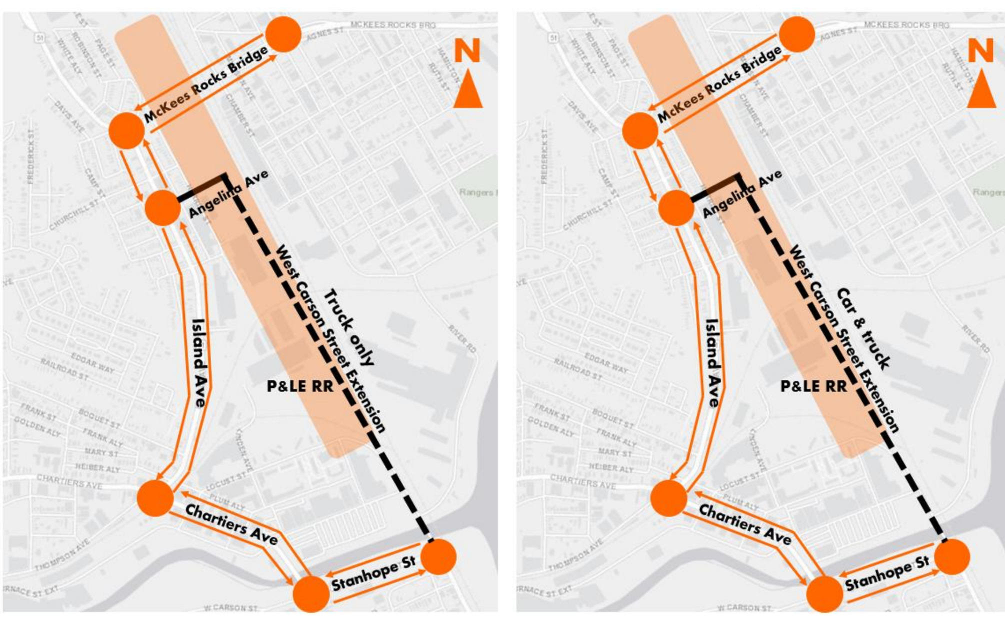


Figure 17 Left: Scenario 1; Right: Scenario 2.

4. Scenario 3: Change of development plans at the P&LE site, with 233,000 sq. ft. manufacturing, 98,000 sq. ft. office, 53,400 sq. ft. warehouse. The new trip generation estimation is:

Development Component	AM Peak Hour			PM Peak Hour		
	In	Out	Total	In	Out	Total
233,000 sf Manufacturing	105	31	136	54	98	152
98,000 sf Office	4	4	8	2	2	4
53,400 sf Warehouse	26	7	33	6	19	25
Total	135	42	177	62	119	181

5. Scenario 4: No left truck turns on Angelina Avenue. Any trucks leaving the P&LE property would be unable to turn left onto Island Avenue.

6. Scenario 5: Scenario 1 & 4 together. West Carson street extension (truck only) + No left truck turns on Angelina Avenue.

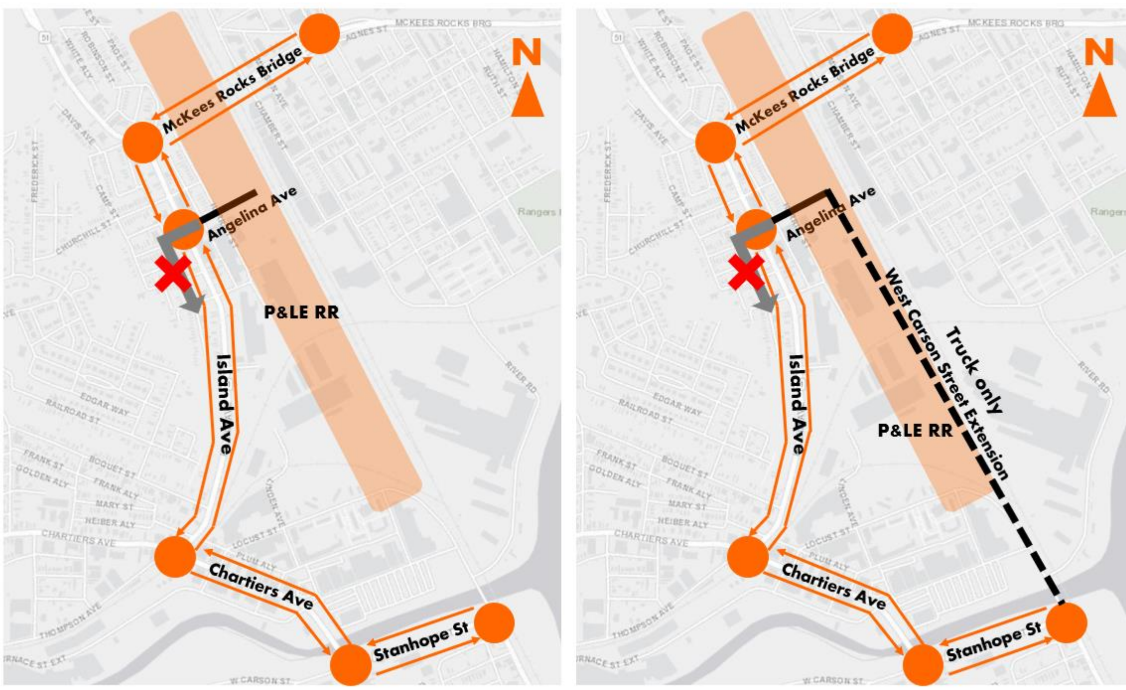


Figure 18 Left: Scenario 4; Right: Scenario 5.

7. Scenario 6: 20% increase of population, portrayed as a 20% increase in car use originating/destinating at McKees Rocks nodes.

8. Scenario 7: 10% increase in industrial/freight traffic in the region.

5.2 Comparisons of Different Scenarios

The travel time percentage changes from **Scenario 0** (full buildout year 2023 without congestion mitigation strategies) for **Scenario 1 to Scenario 7** for all trips of the studied roadways and intersections in McKees Rocks district are summarized in Table 4. Except for Scenario 6 and Scenario 7 which show the influence of demographical changes, the Scenario 1 to Scenario 5 show the influence of different traffic congestion mitigation strategies. The influences are different for different scenarios, and in Scenario 5 the travel time is reduced the most, which means a new West Carson street extension (truck only) combined with prohibiting left truck turns on Angelina Avenue could be the most effective congestion mitigation strategy among the 5 different strategies.

Change	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
AM Peak Car	-2.8%	-1.9%	-0.3%	0.1%	**-5.4%**	22.4%	4.5%
AM Peak Truck	-0.4%	0.2%	-0.8%	2.7%	**-4.8%**	18.0%	5.0%
PM Peak Car	-2.2%	-3.8%	0.2%	-1.6%	**-8.0%**	14.0%	3.2%
PM Peak Truck	-0.9%	-4.2%	-0.8%	1.2%	**-2.5%**	15.7%	5.6%

Table 4 Overall travel time percentage change from Scenario 0 (full buildout year 2023 without congestion mitigation strategies) for Scenario 1 to Scenario 7.

The 1) AM Peak hour average travel time percentage change from Scenario 0 between nodes, 2) PM Peak hour average travel time percentage change from Scenario 0 between nodes, 3) Average delay per vehicle percentage change from Scenario 0 at intersections, 4) Probability of heavy congestion on the link that vehicles queue up to upstream links during Peak hours; 5) Peak hour average travel time percentage change from Scenario 0 to key travel nodes for Scenario 1 – Scenario 7 are provided in the Appendix at the end of this report.

6. Conclusions

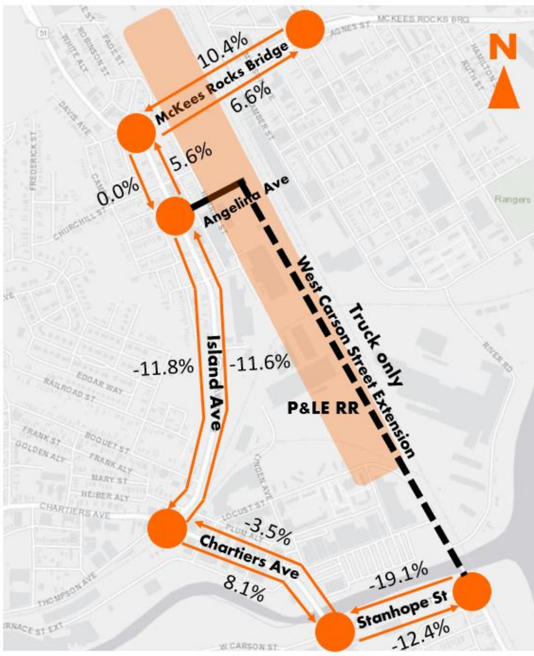
This project conducts an in-depth analysis of the potential traffic impact of the new CSX intermodal railway terminal to be built in McKees Rocks district in high temporal and spatial resolutions. Using the data sets possessed by CMU Mobility Data Analytics Center, we simulate individual cars and trucks, and model their route choices, travel time and mixed traffic flow conditions. The result includes the travel time, travel delay, vehicle-mile-traveled and emissions for each road segment and intersection by time of day, for both the existing traffic conditions in baseline year 2016, as well as the future traffic conditions in full buildout year 2023. We also examine the effectiveness of potential traffic management strategies in different scenarios. We find that a new West Carson street extension (truck only) combined with prohibiting left truck turns on Angelina Avenue could be the most effective congestion mitigation strategy among the different strategies.

While we focus on several particular applications (trucks and roadway) to demonstrate the method and leverage our resources, the methodology can be broadly applicable and scalable to other cities or regions. This generality will attract attentions from various groups interested in smart infrastructure, green design, and environmental policies.

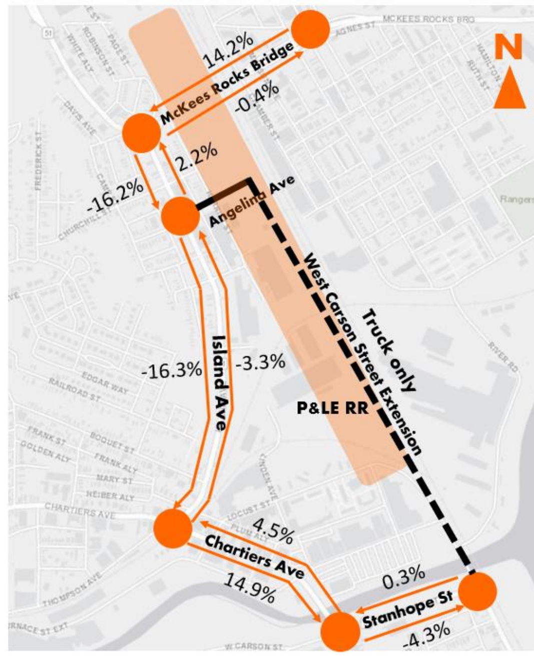
Appendix

Scenario 1 Results

AM Peak hour average travel time percentage change from Scenario 0 between intersections:

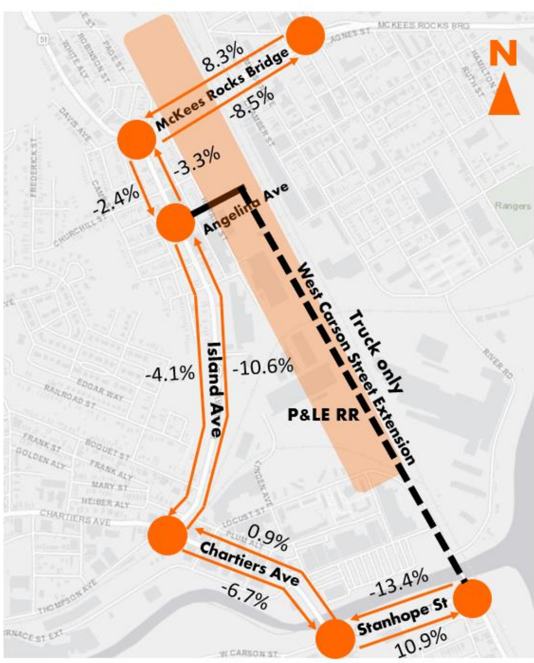


Car

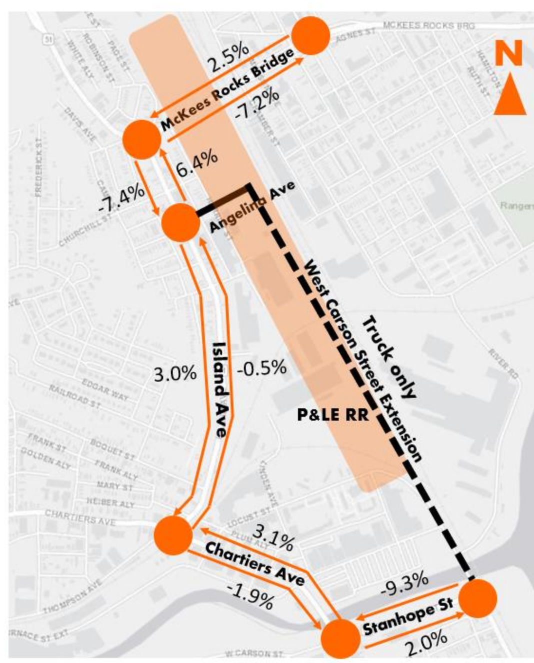


Truck

PM Peak hour average travel time percentage change from Scenario 0 between intersections:



Car

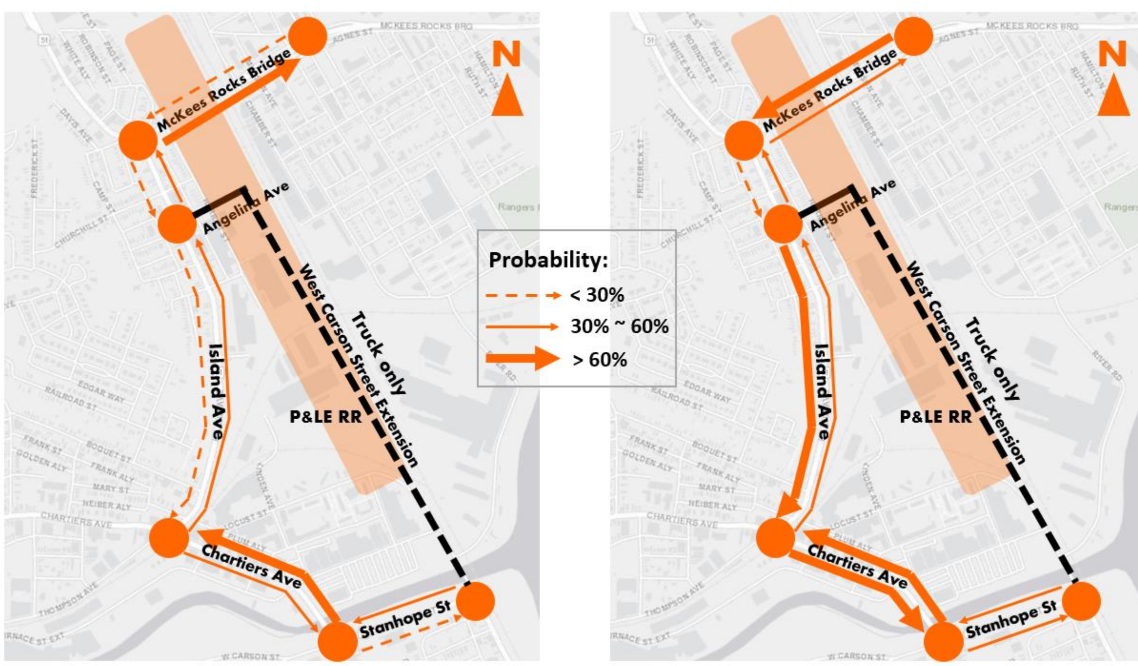


Truck

Average delay per vehicle percentage change from Scenario 0 at intersections:

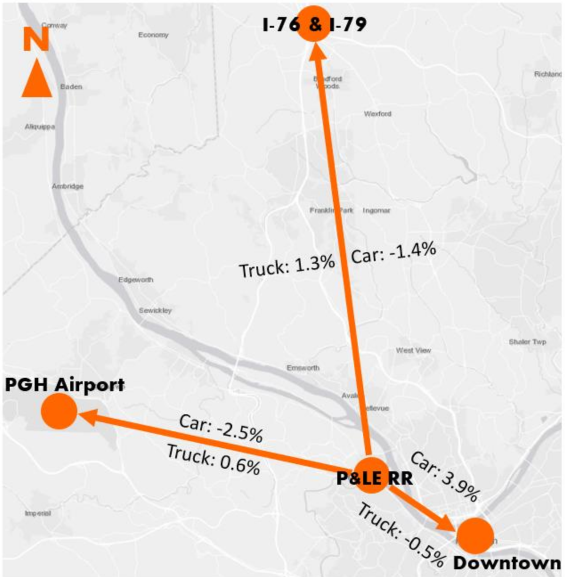
AM Peak PM Peak

Probability of heavy congestion on the link that vehicles queue up to upstream links during Peak hours:

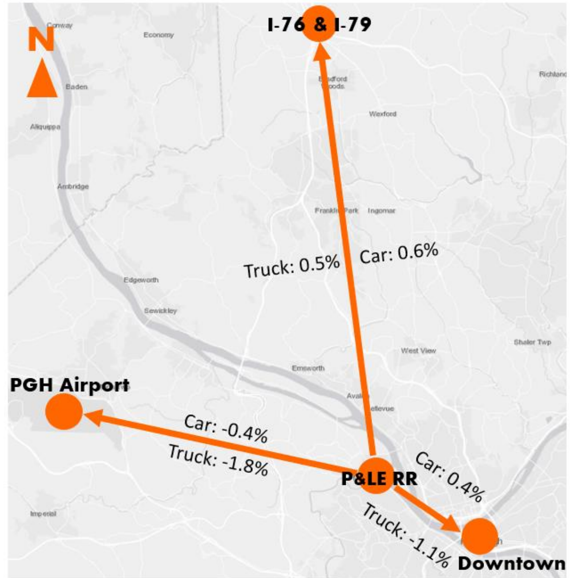


AM Peak PM Peak

Peak hour average travel time percentage change from Scenario 0 to key travel nodes:



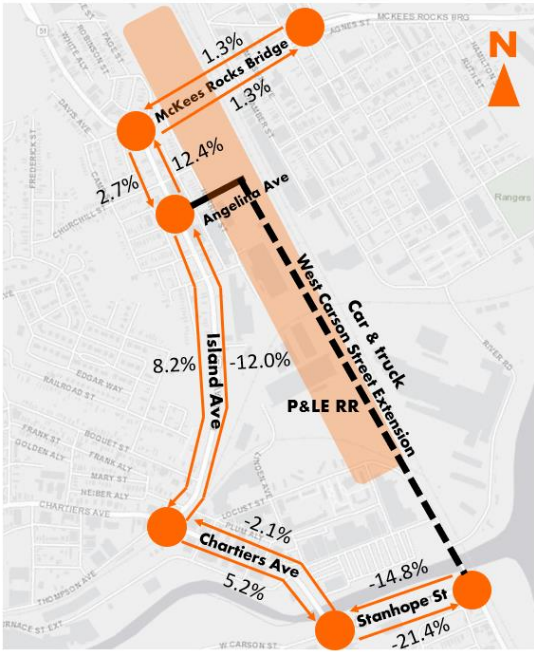
AM Peak



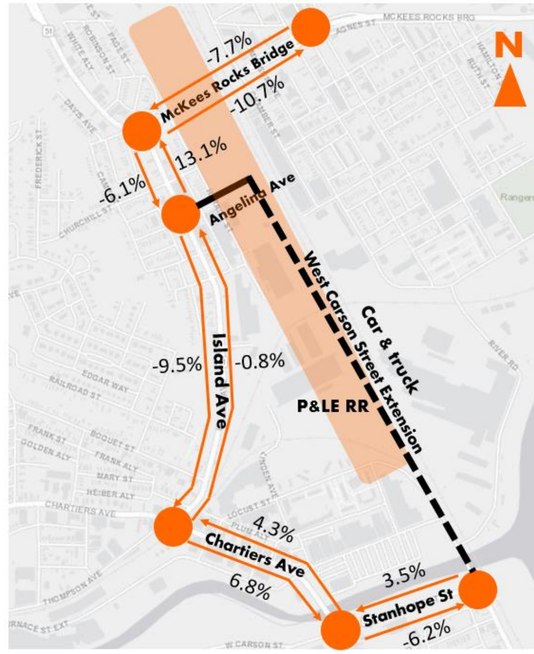
PM Peak

Scenario 2 Results

AM Peak hour average travel time percentage change from Scenario 0 between nodes:

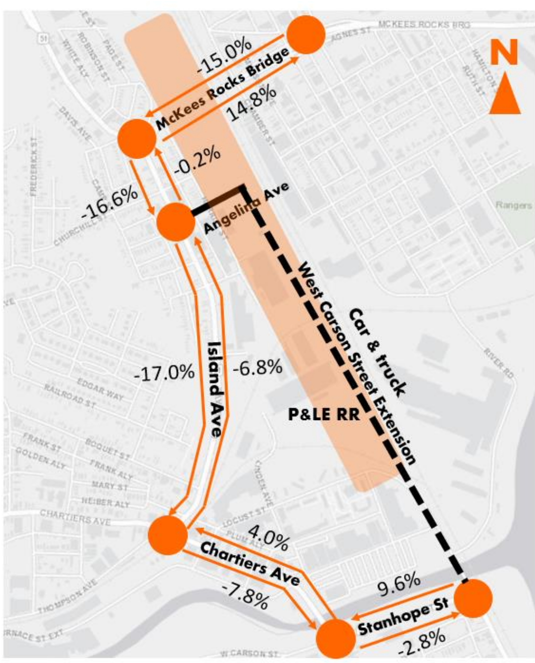


Car

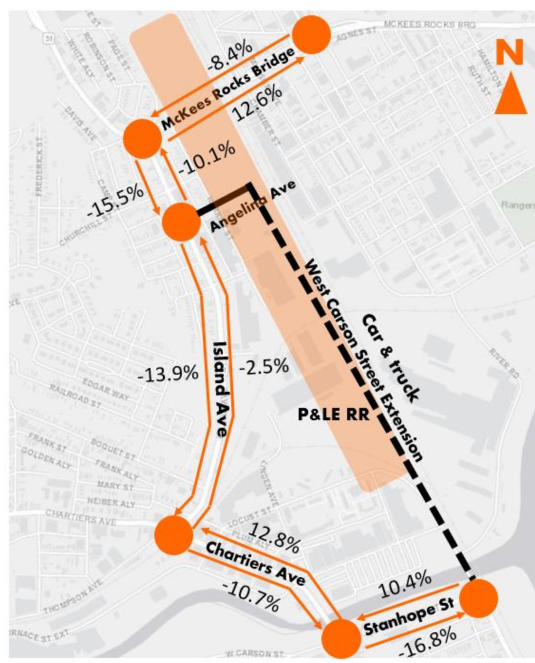


Truck

PM Peak hour average travel time percentage change from Scenario 0 between nodes:



Car

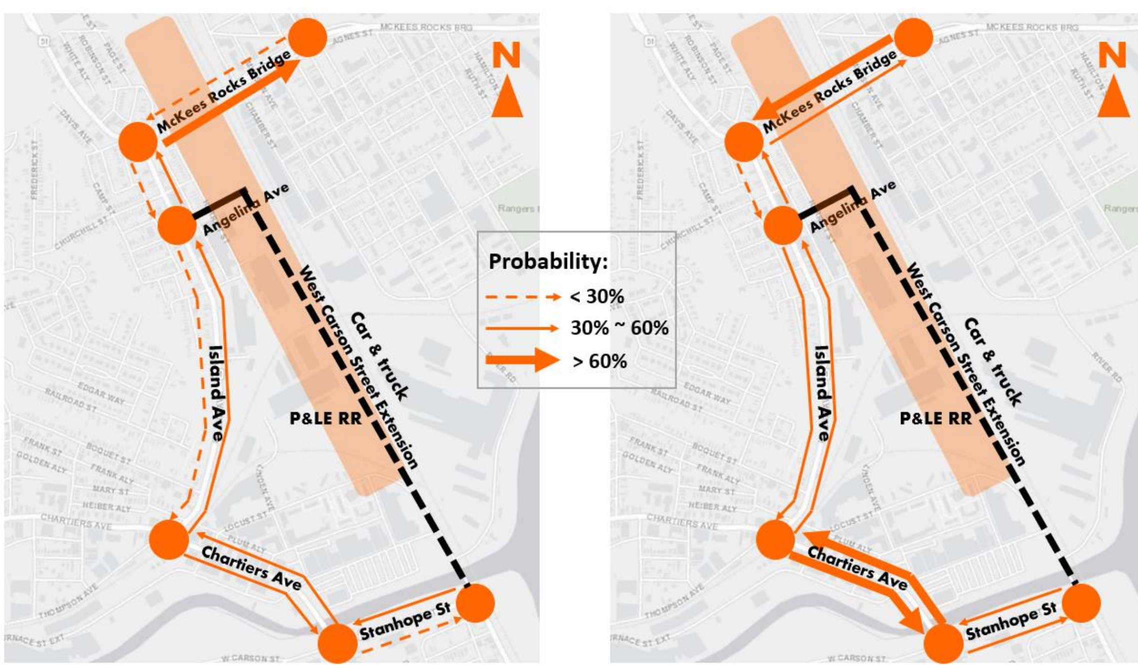


Truck

Average delay per vehicle percentage change from Scenario 0 at intersections:

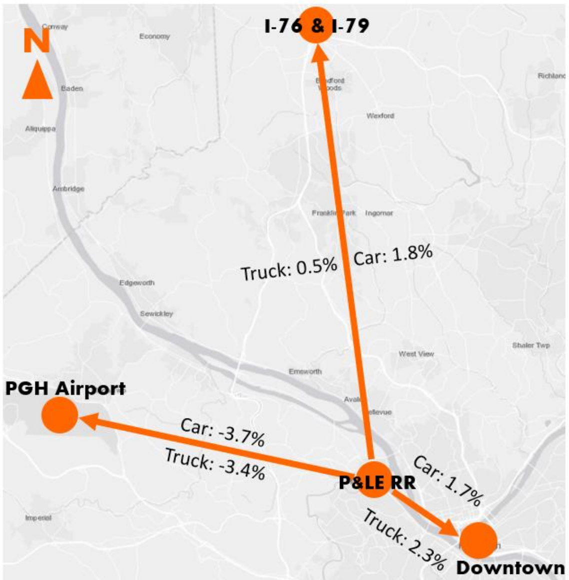
AM Peak PM Peak

Probability of heavy congestion on the link that vehicles queue up to upstream links during Peak hours:

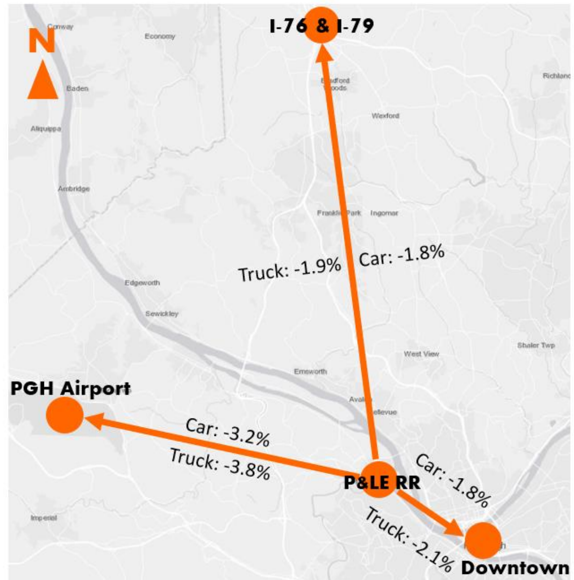


AM Peak PM Peak

Peak hour average travel time percentage change from Scenario 0 to key travel nodes:



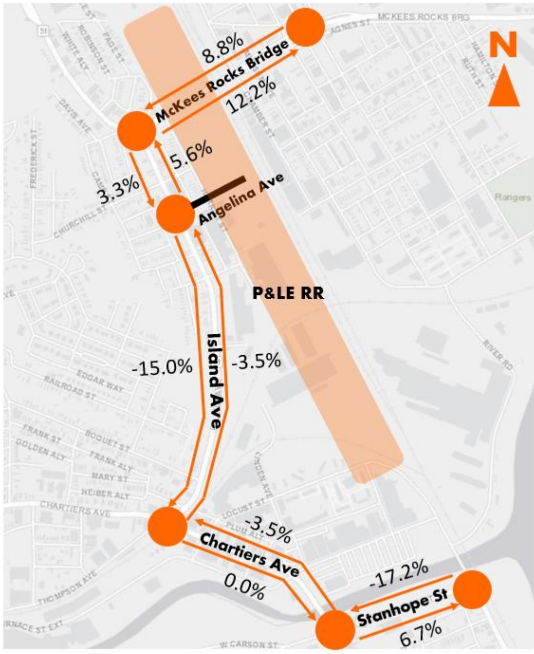
AM Peak



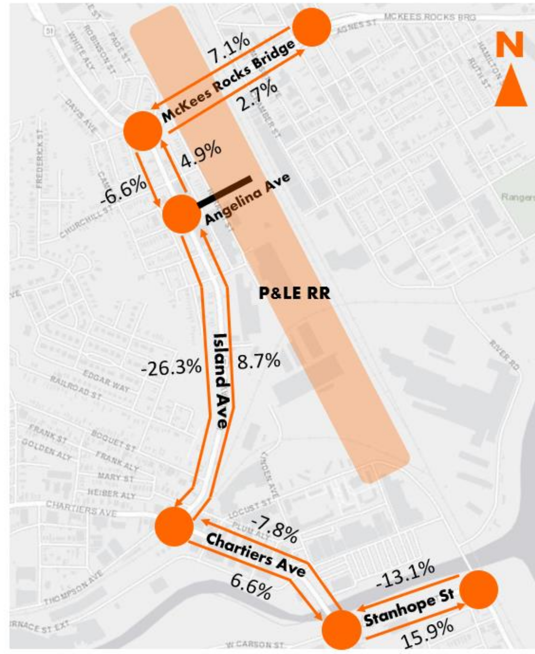
PM Peak

Scenario 3 Results

AM Peak hour average travel time percentage change from Scenario 0 between nodes:

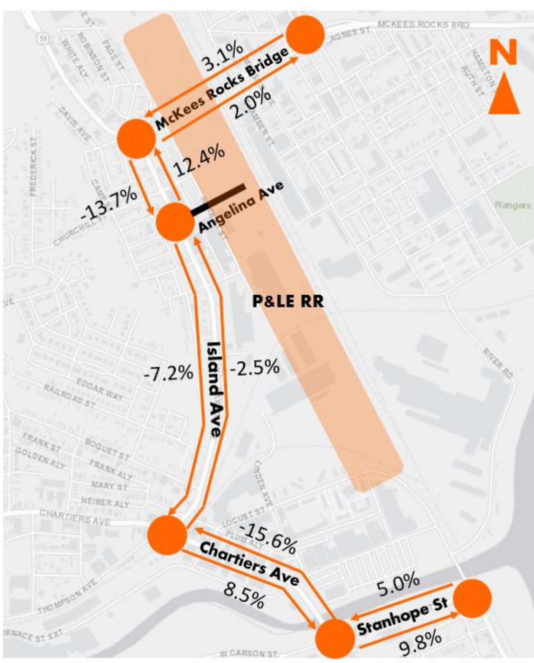


Car

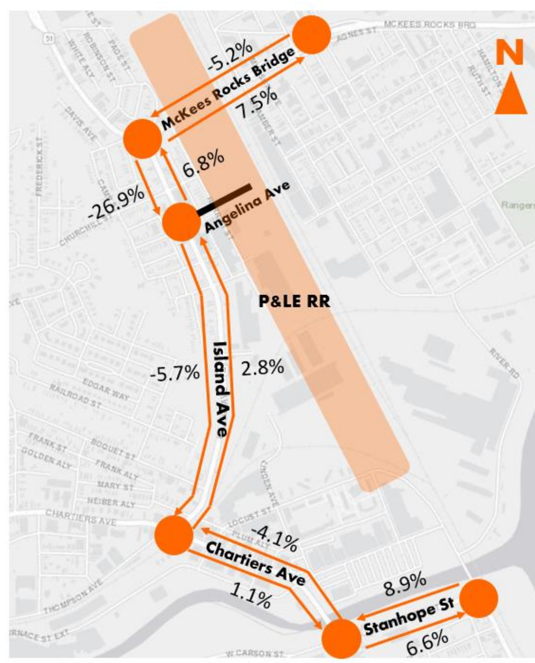


Truck

PM Peak hour average travel time percentage change from Scenario 0 between nodes:

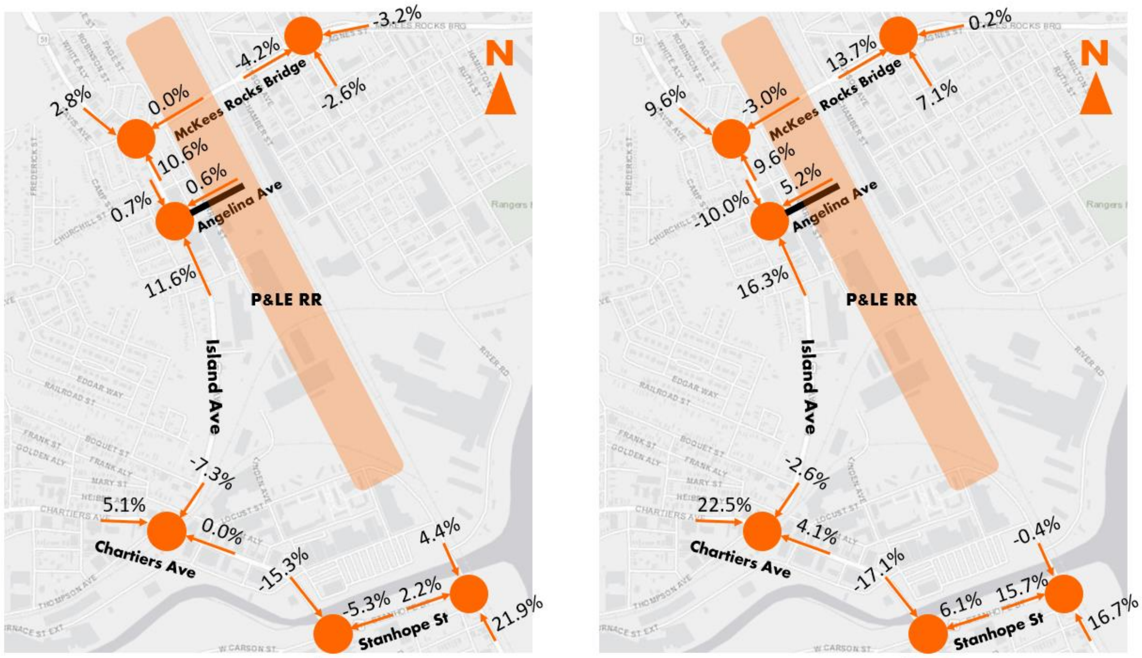


Car



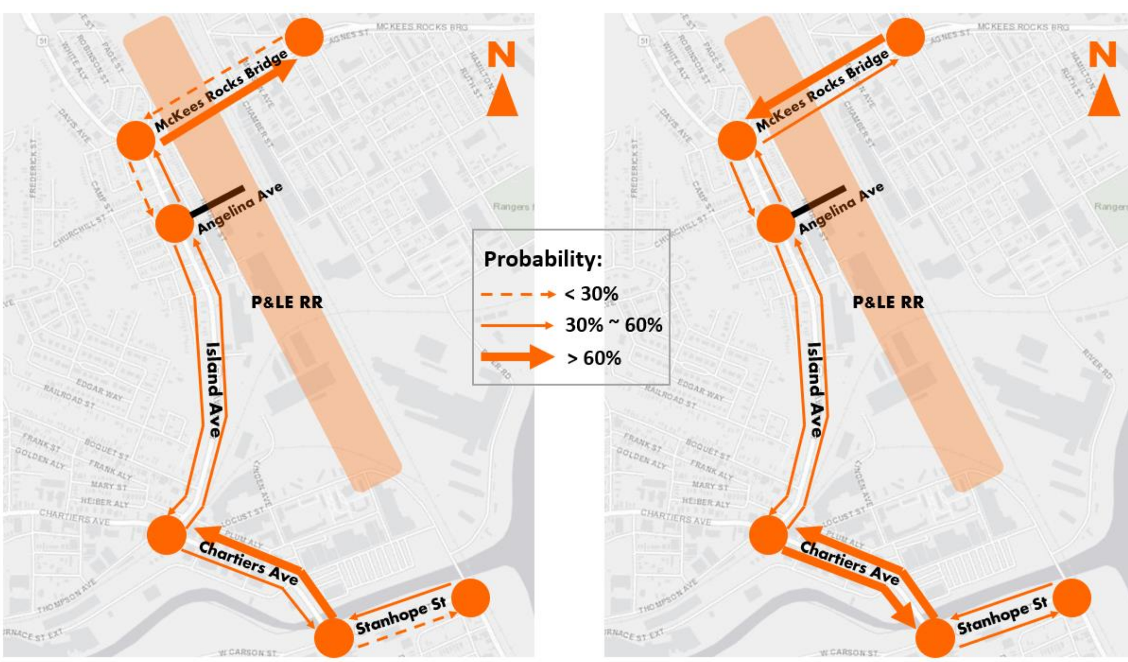
Truck

Average delay per vehicle percentage change from Scenario 0 at intersections:



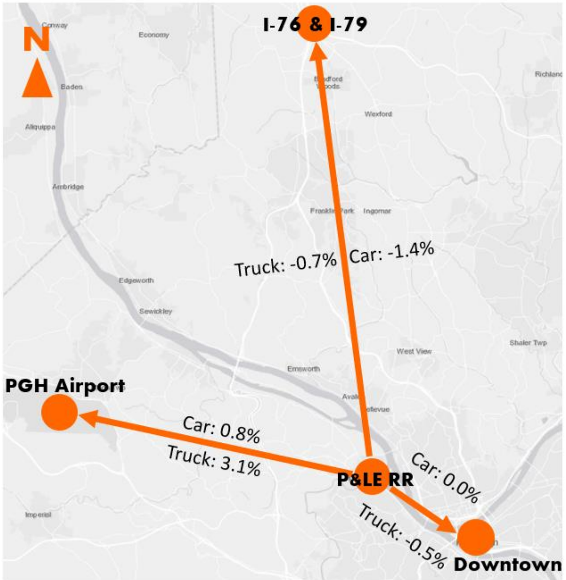
AM Peak PM Peak

Probability of heavy congestion on the link that vehicles queue up to upstream links during Peak hours:

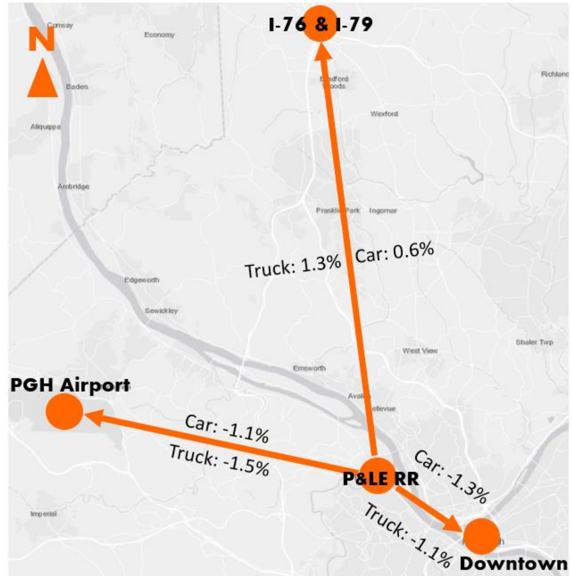


AM Peak PM Peak

Peak hour average travel time percentage change from Scenario 0 to key travel nodes:



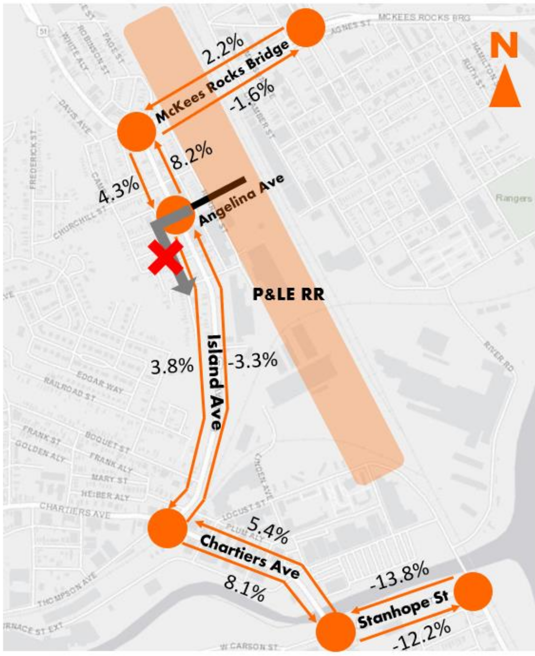
AM Peak



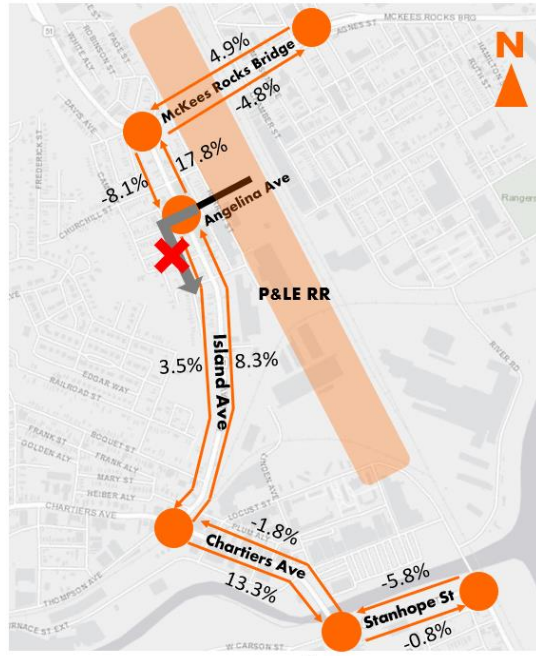
PM Peak

Scenario 4 Results

AM Peak hour average travel time percentage change from Scenario 0 between nodes:

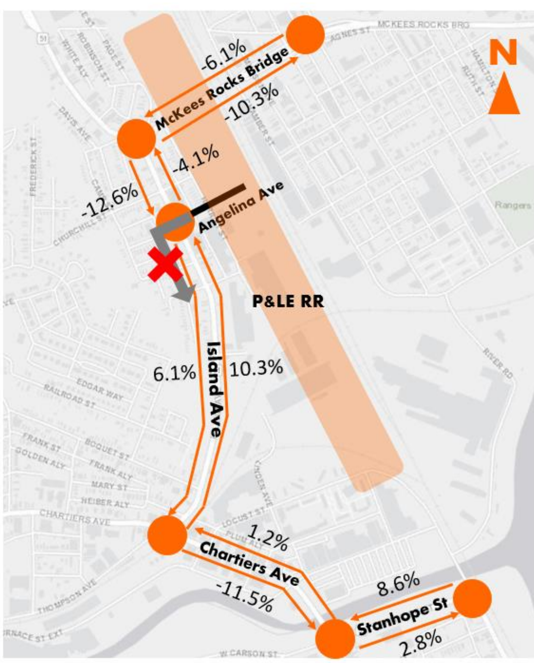


Car

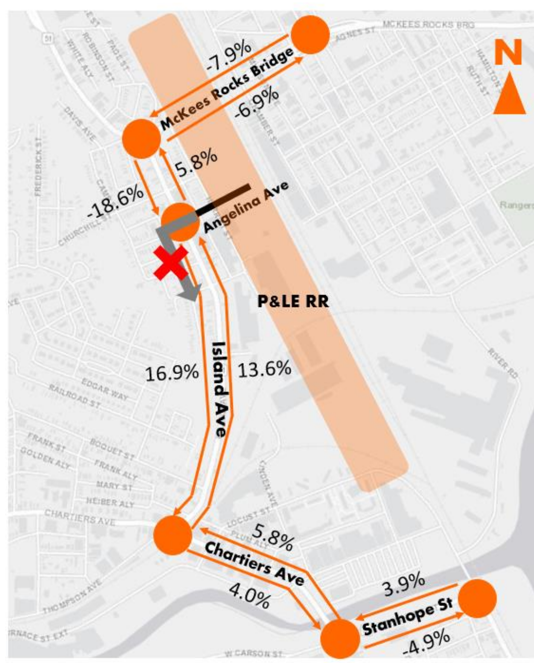


Truck

PM Peak hour average travel time percentage change from Scenario 0 between nodes:

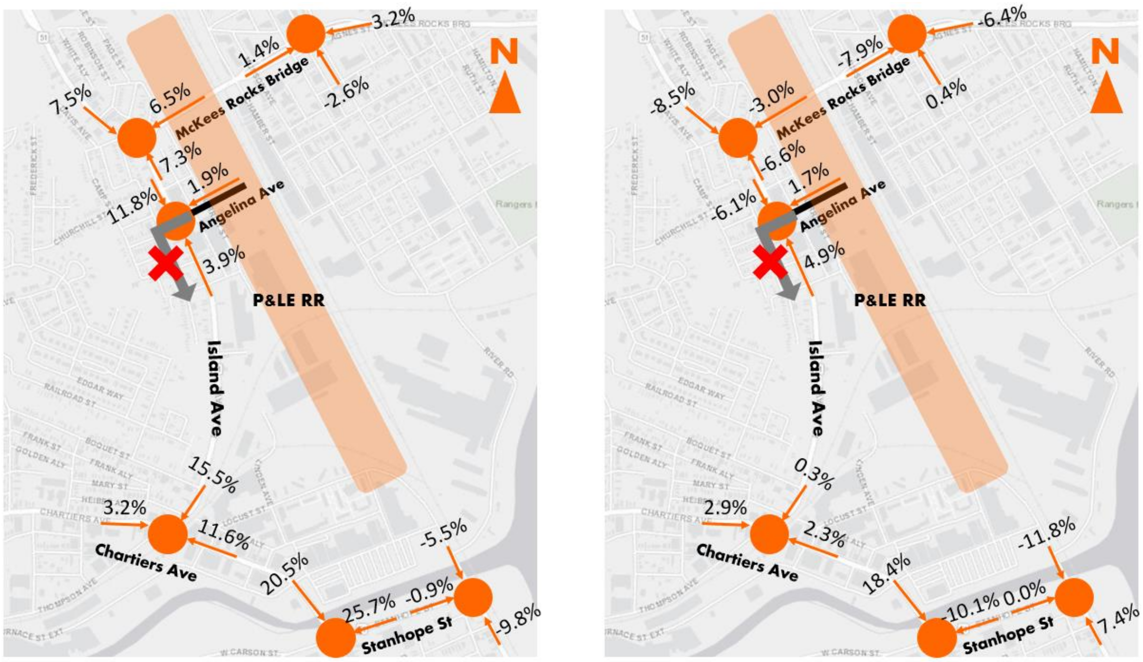


Car



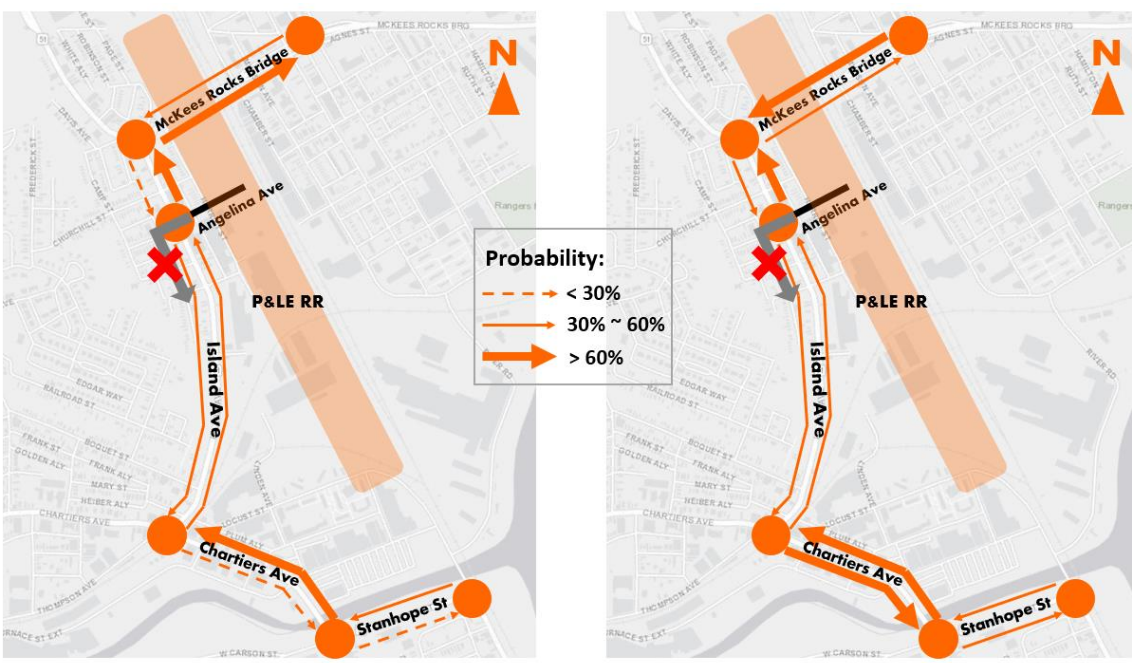
Truck

Average delay per vehicle percentage change from Scenario 0 at intersections:



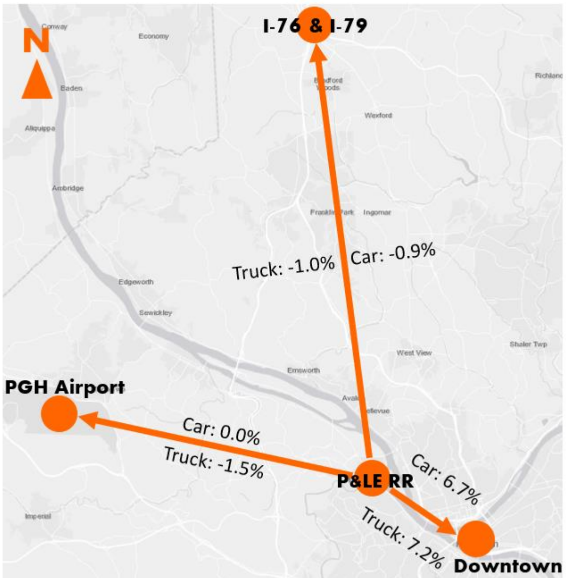
AM Peak PM Peak

Probability of heavy congestion on the link that vehicles queue up to upstream links during Peak hours:

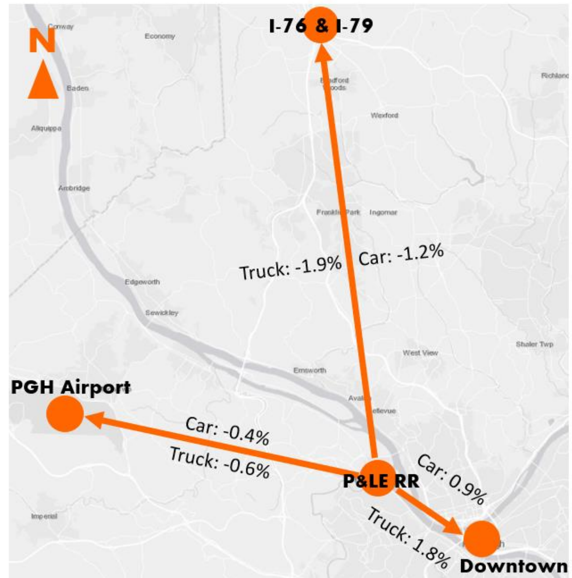


AM Peak PM Peak

Peak hour average travel time percentage change from Scenario 0 to key travel nodes:



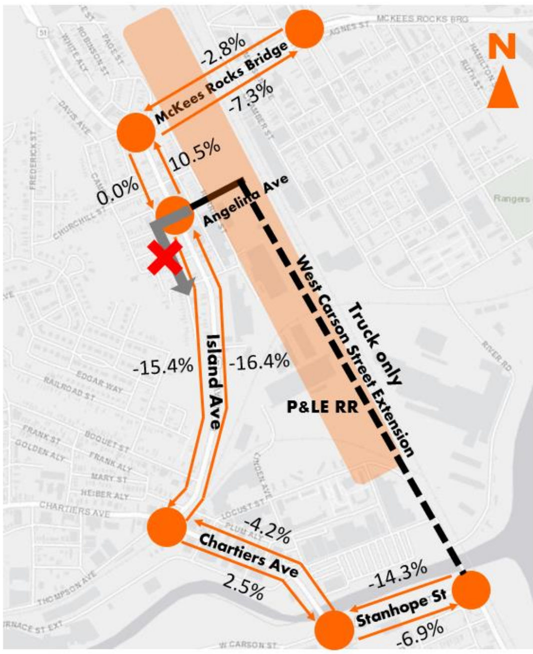
AM Peak



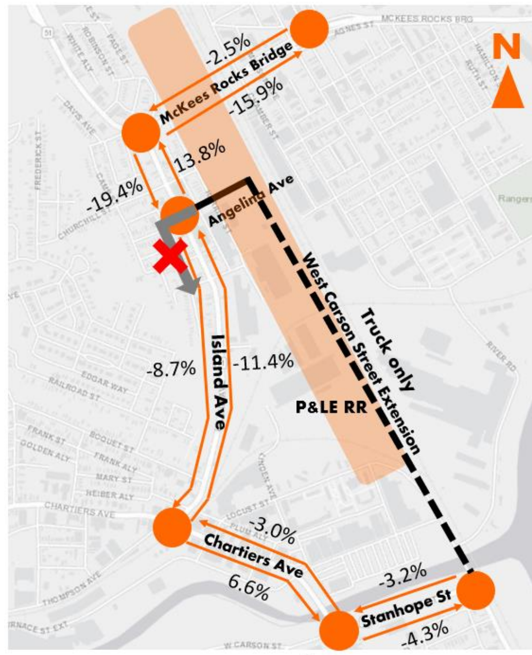
PM Peak

Scenario 5 Results

AM Peak hour average travel time percentage change from Scenario 0 between nodes:

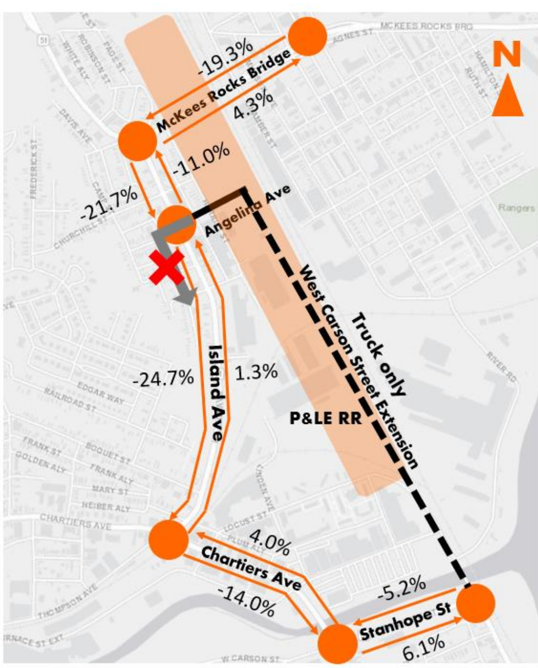


Car

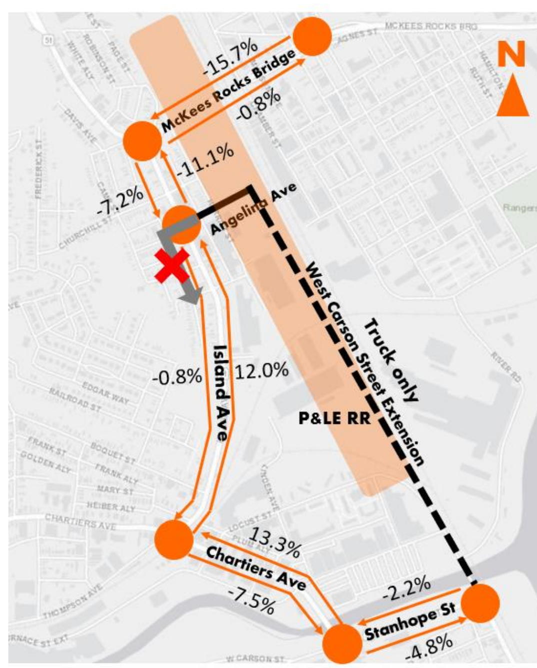


Truck

PM Peak hour average travel time percentage change from Scenario 0 between nodes:

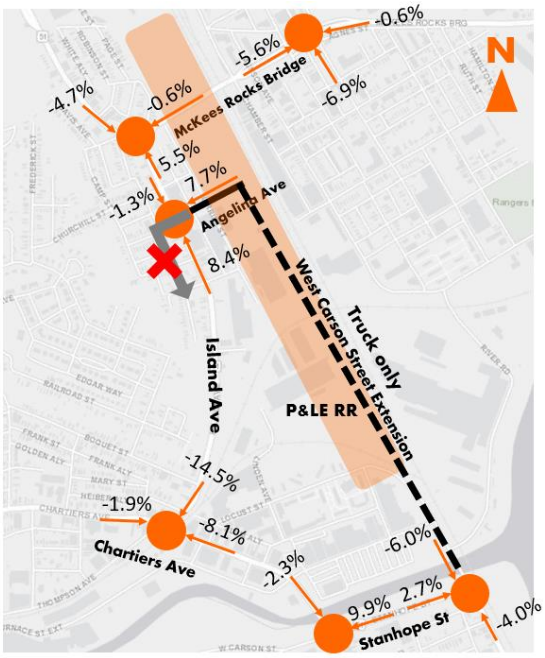


Car

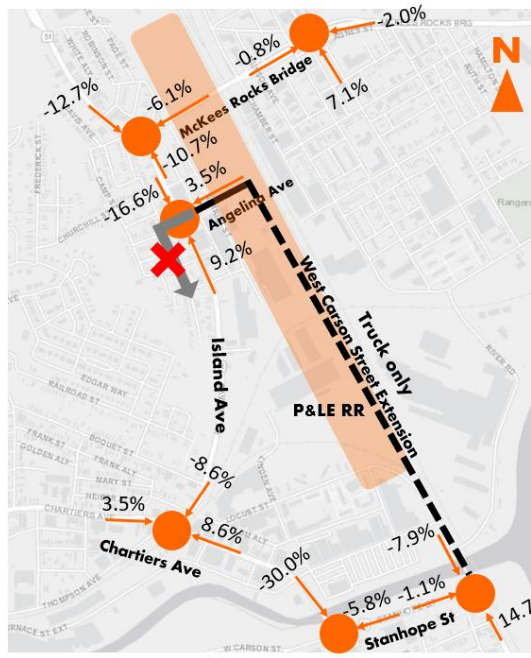


Truck

Average delay per vehicle percentage change from Scenario 0 at intersections:

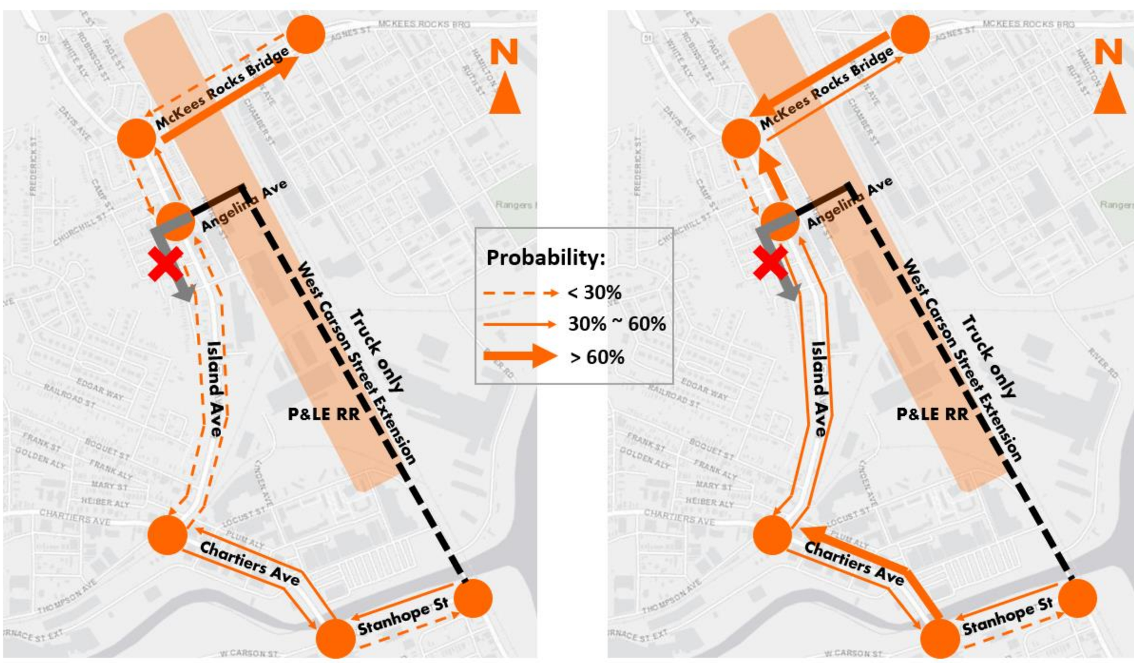


AM Peak



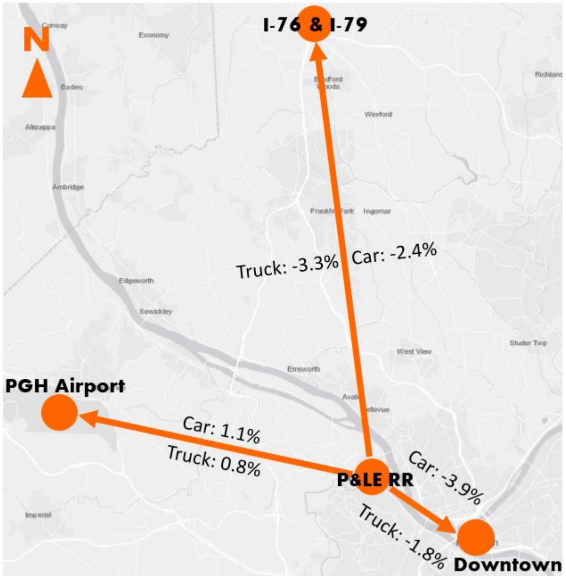
PM Peak

Probability of heavy congestion on the link that vehicles queue up to upstream links during Peak hours:

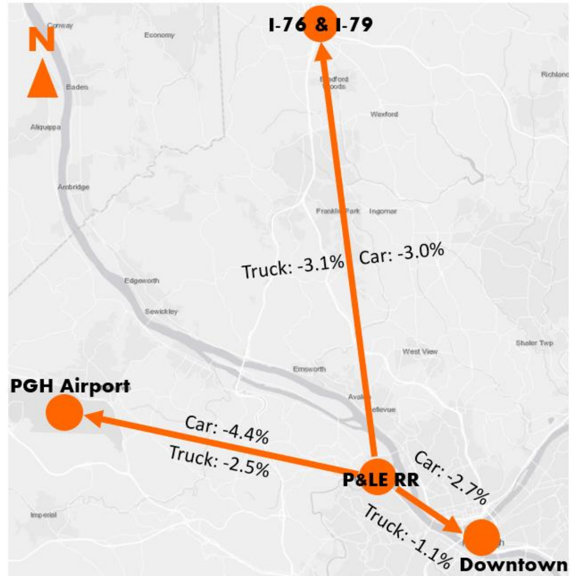


AM Peak PM Peak

Peak hour average travel time percentage change from Scenario 0 to key travel nodes:



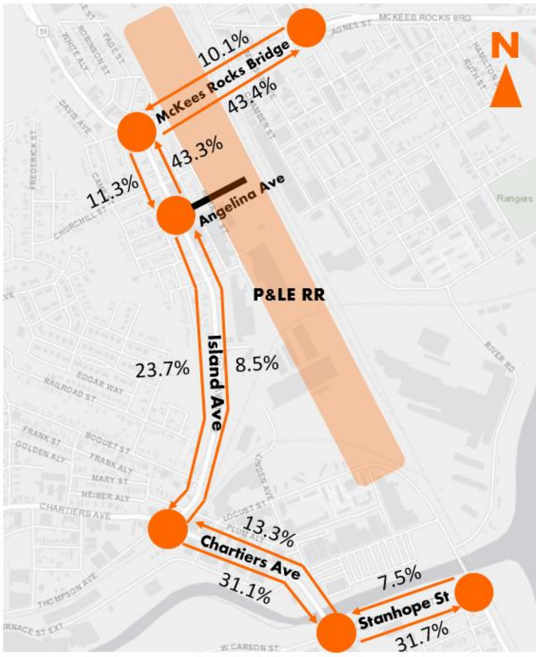
AM Peak



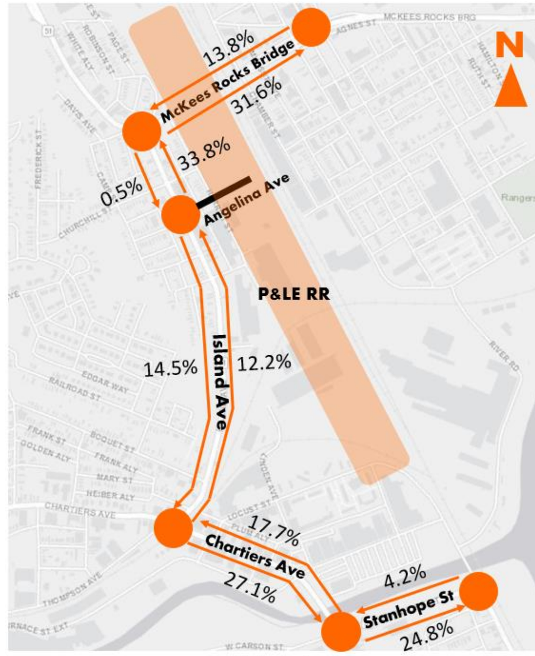
PM Peak

Scenario 6 Results

AM Peak hour average travel time percentage change from Scenario 0 between nodes:

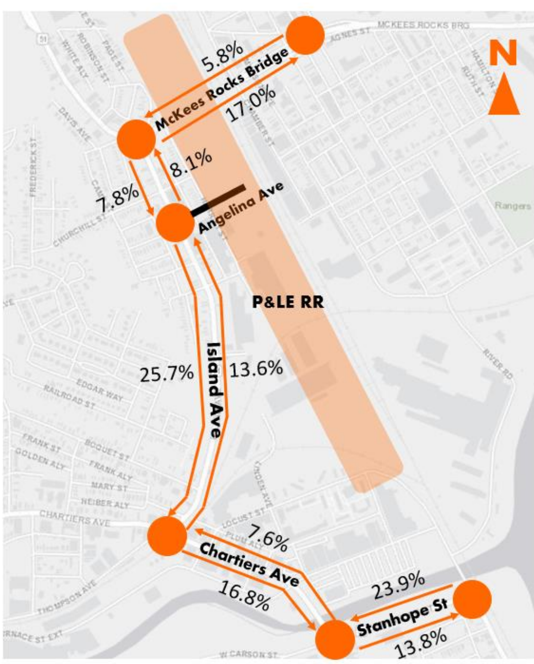


Car

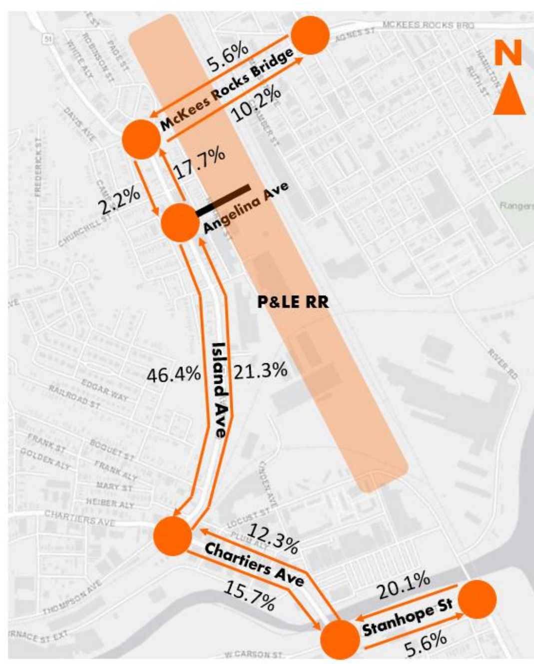


Truck

PM Peak hour average travel time percentage change from Scenario 0 between nodes:

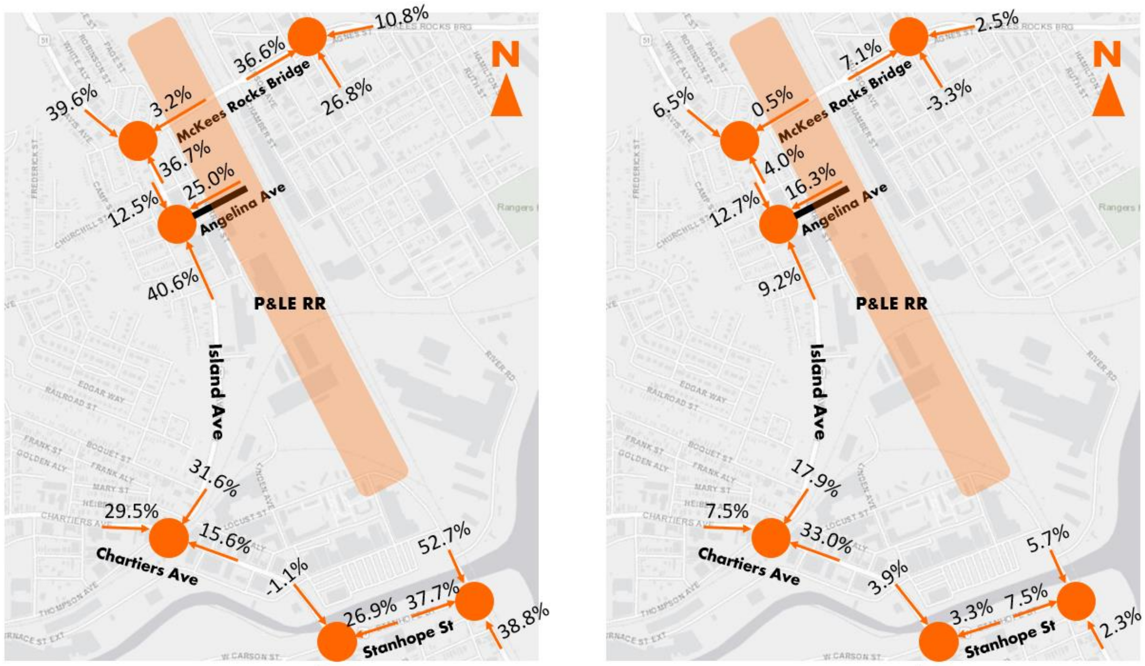


Car



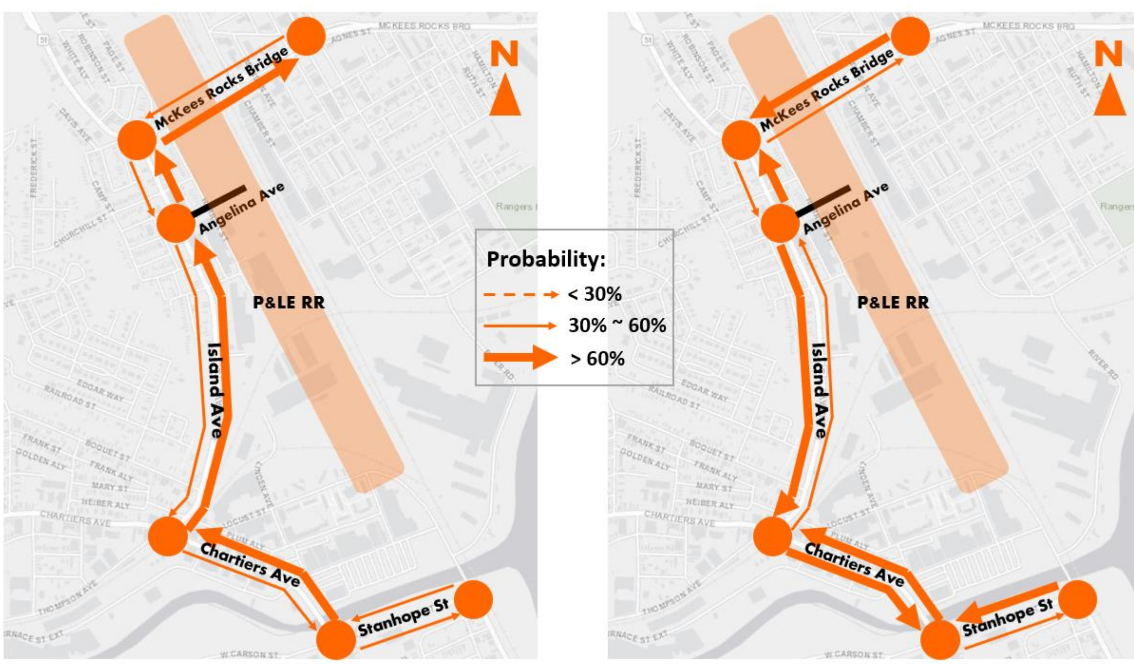
Truck

Average delay per vehicle percentage change from Scenario 0 at intersections:



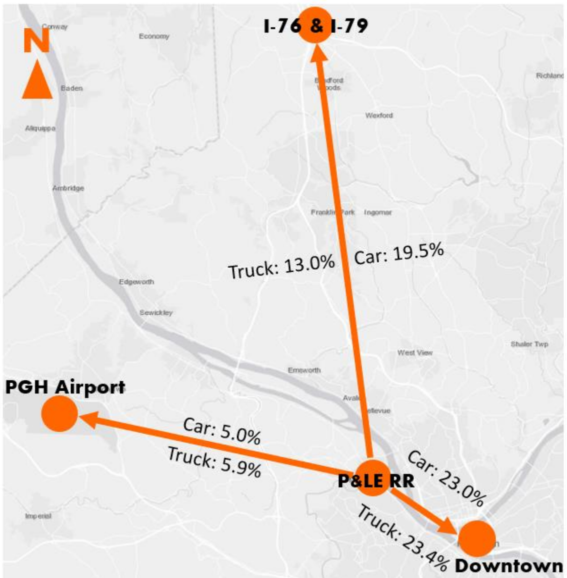
AM Peak **PM Peak**

Probability of heavy congestion on the link that vehicles queue up to upstream links during Peak hours:

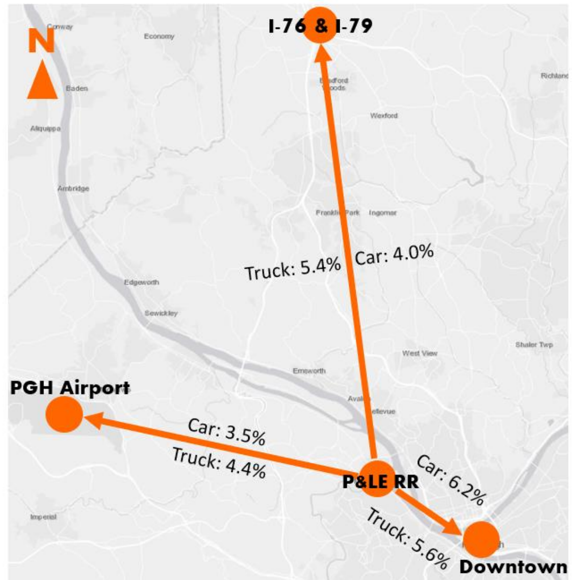


AM Peak **PM Peak**

Peak hour average travel time percentage change from Scenario 0 to key travel nodes:



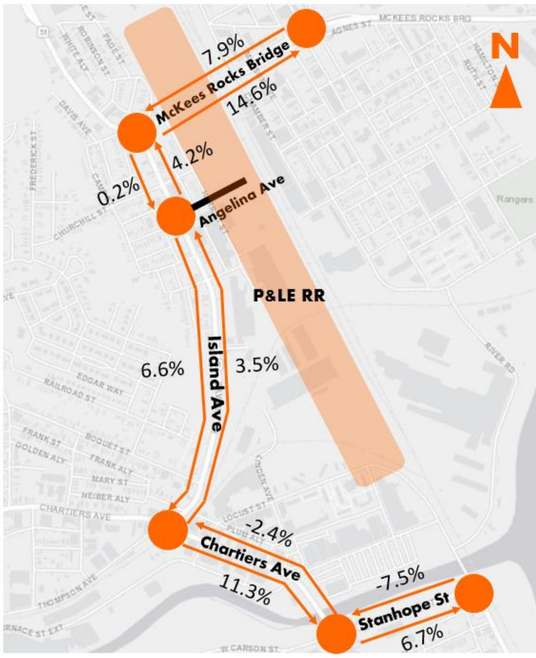
AM Peak



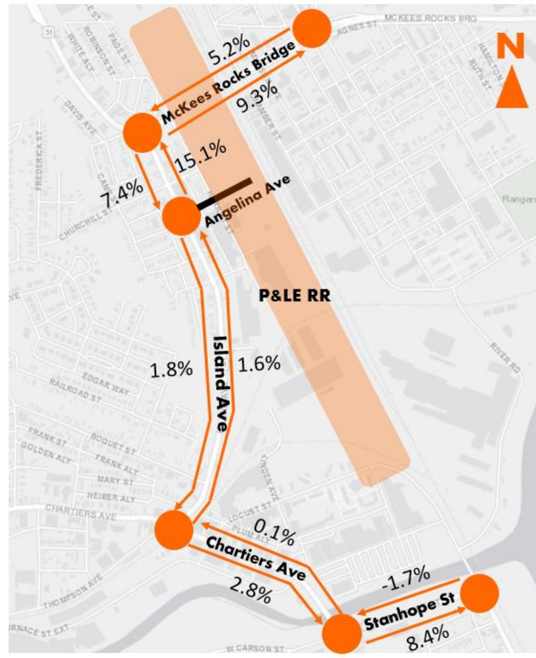
PM Peak

Scenario 7 Results

AM Peak hour average travel time percentage change from Scenario 0 between intersections:

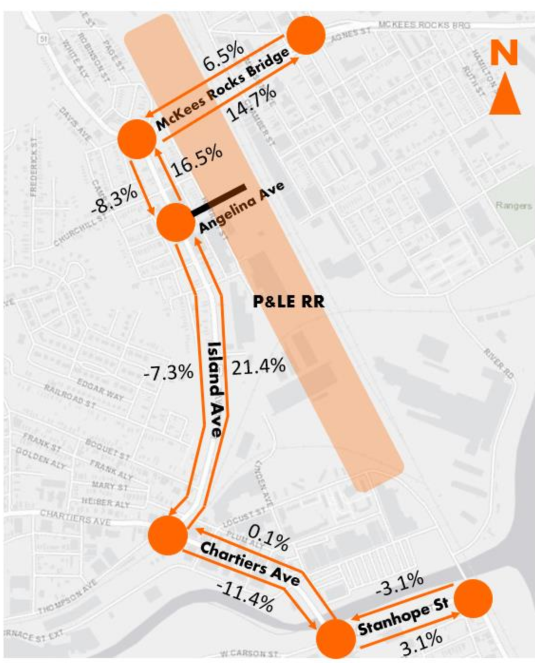


Car

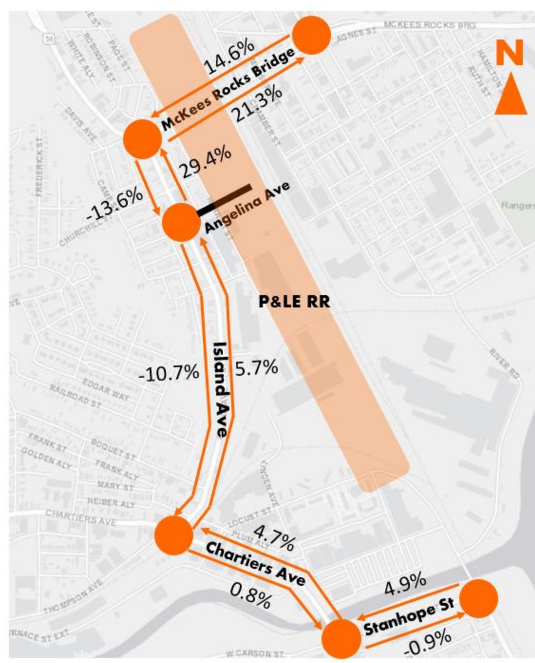


Truck

PM Peak hour average travel time percentage change from Scenario 0 between nodes:

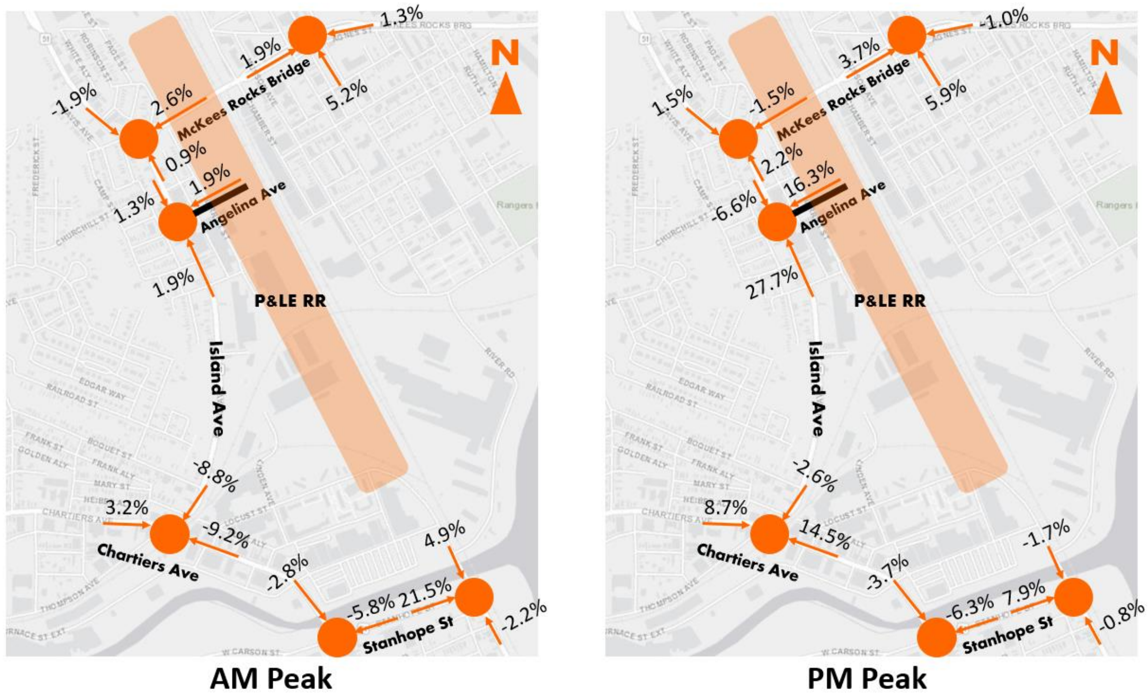


Car

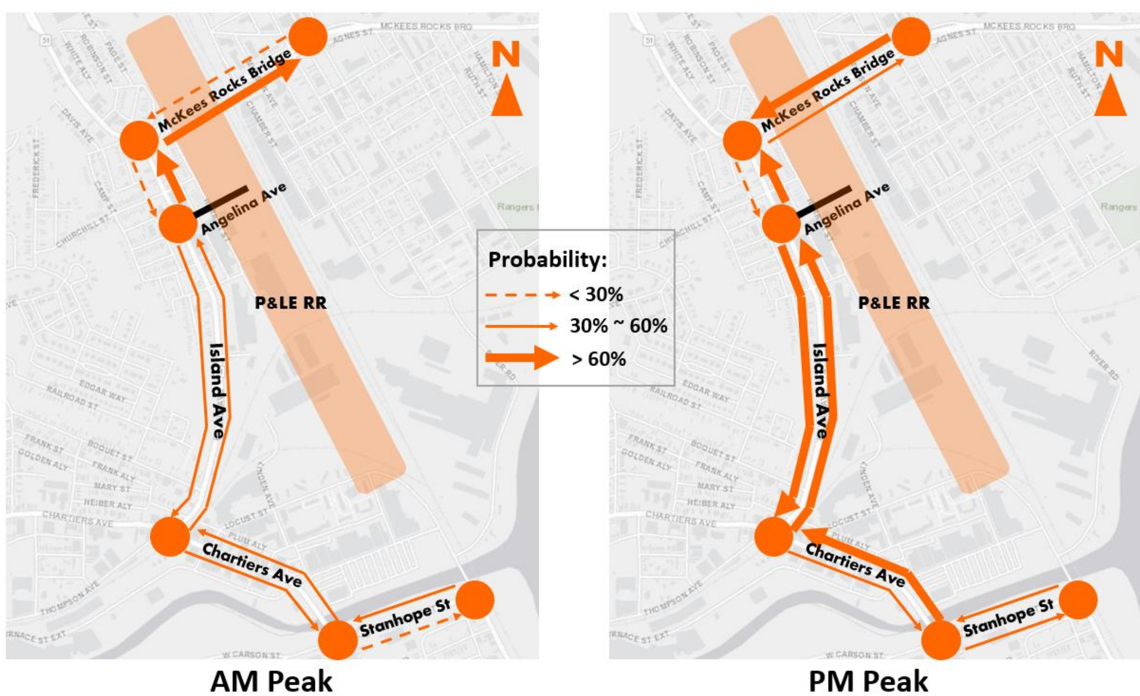


Truck

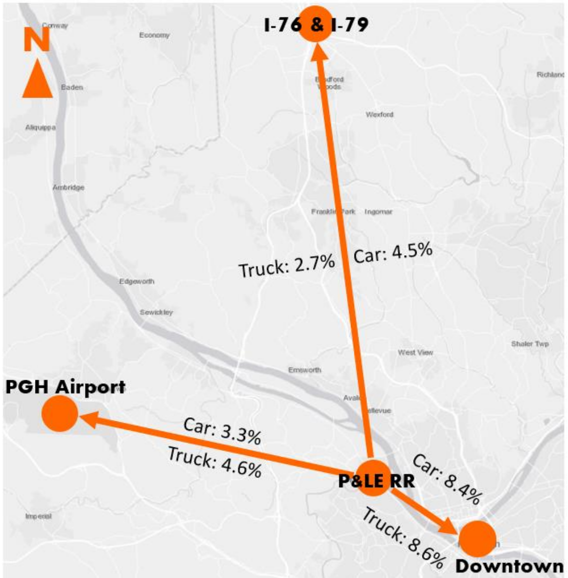
Average delay per vehicle percentage change from Scenario 0 at intersections:



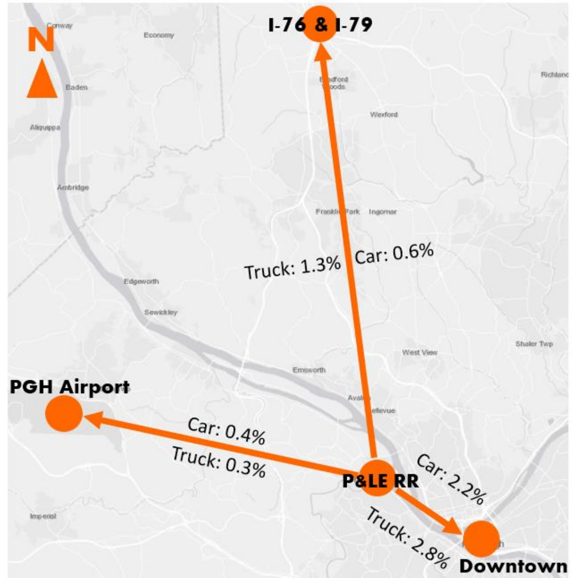
Probability of heavy congestion on the link that vehicles queue up to upstream links during Peak hours:



Peak hour average travel time percentage change from Scenario 0 to key travel nodes:



AM Peak



PM Peak