Factors Affecting the Constructability of Alternative Intersections & Interchanges

February 29, 2024

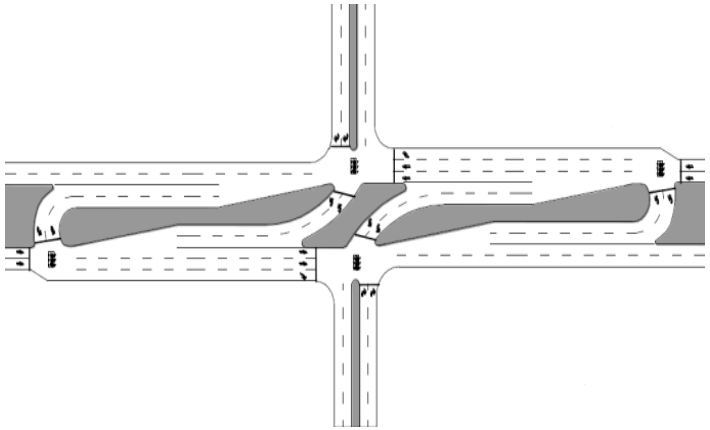
William Rasdorf, Ph.D., P.E.
Minerva Bonilla, Ph.D.

Department of Civil, Construction, and Environmental Engineering
North Carolina State University

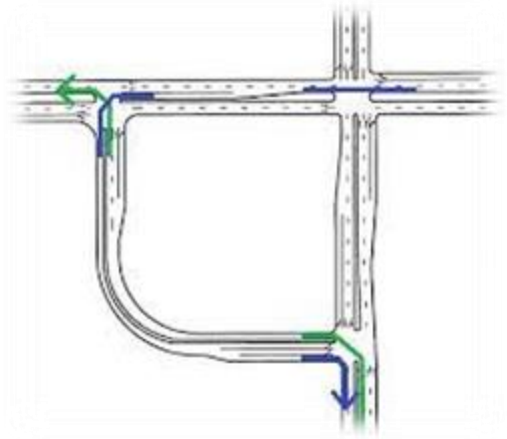
Outline

1. Background
    - Definition
    - Problem
    - Objectives
2. Findings
    - Inhibitors Identification
    - Case studies (Work Zone Evaluation)
3. Conclusion

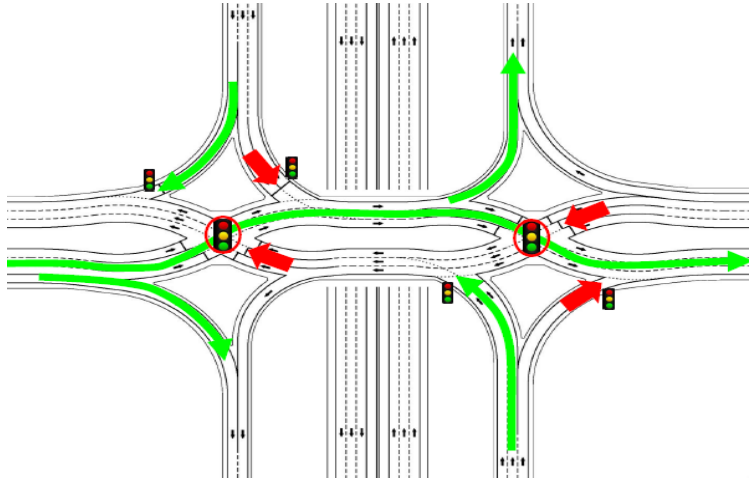
Alternative Intersections and Interchanges (AIIs)



Reduced Conflict Intersection



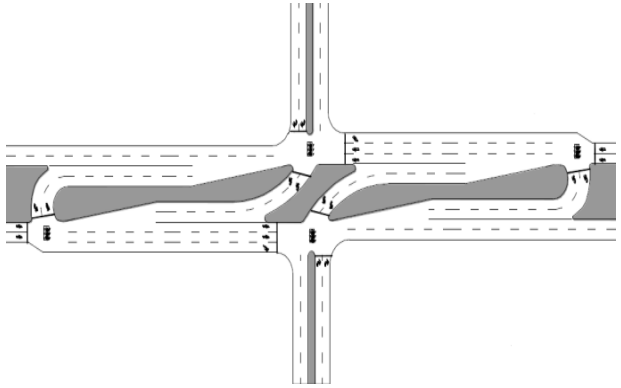
Quadrants Roadways



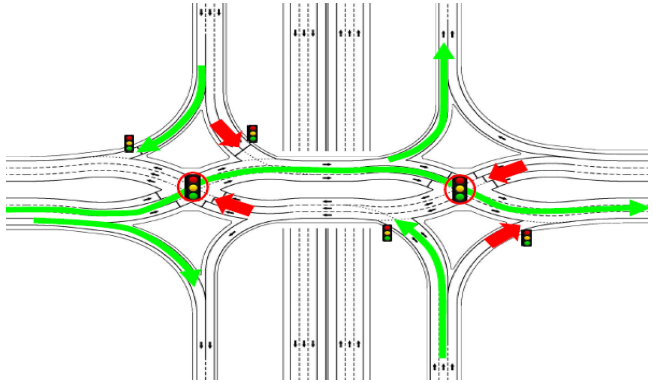
Diverging Diamond Interchange

Continuous Flow Intersection

Alternative Intersections and Interchanges (AIIs)

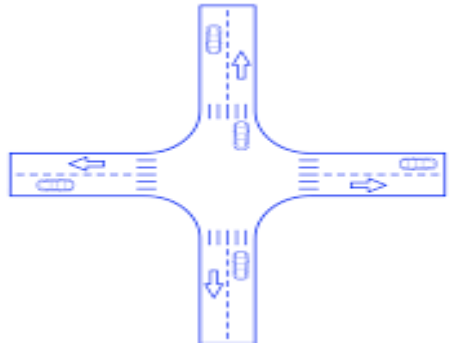


Reduced Conflict Intersection

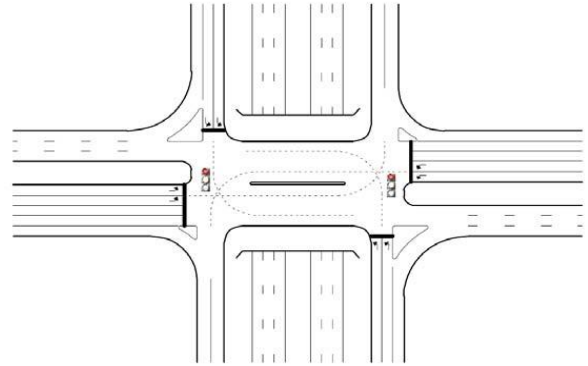


Diverging Diamond Interchange

Conventional Intersections and Interchanges (CIIs)



Conventional Intersection



Conventional Interchange

Background

- AIIs enhance traffic flow, reduce congestion, increase capacity and safety, and account for future traffic demands.
- The use of Alternative Intersections and Interchanges (AIIs) is crucial for the sustainability of transportation infrastructure.

Problem

- AIIs are not being built with the frequency they could be.
  - A perception exists that AIIs result in additional construction time and cost when compared to projects with conventional designs.

Why does this perception exist?

Because AIIs are unfamiliar.

Inhibitors

Are the factors that have the potential to negatively affect the construction of AII projects.

Affect

Project

Result

Objective

- Identify and quantify construction inhibitors previously identified on NCDOT projects.
- Analyze inhibitors documented in claims and supplemental agreements.
- Identify and quantify cost and schedule differences between AIIs and Conventional Designs.

Literature Review Findings

Perceptions vs Findings

TRUE

Design mistakes and omissions cause constructability problems such as cost and schedule overruns

FALSE

Contractor's lack of familiarity with AII designs

Partially TRUE

Space constraints are an issue

Partially TRUE

Traffic flow during construction is a problem

TRUE

Safety of workers and the public is an issue

TRUE

There is a lack of construction data for AII projects

Methodology

Interviews

- A total of 29 interviews
  - (NCDOT personnel, contractors, and consultants)

Surveys

- A total of 48 responses
  - 28 responses (NCDOT personnel and contractors)
  - 20 responses (Other state DOTs)

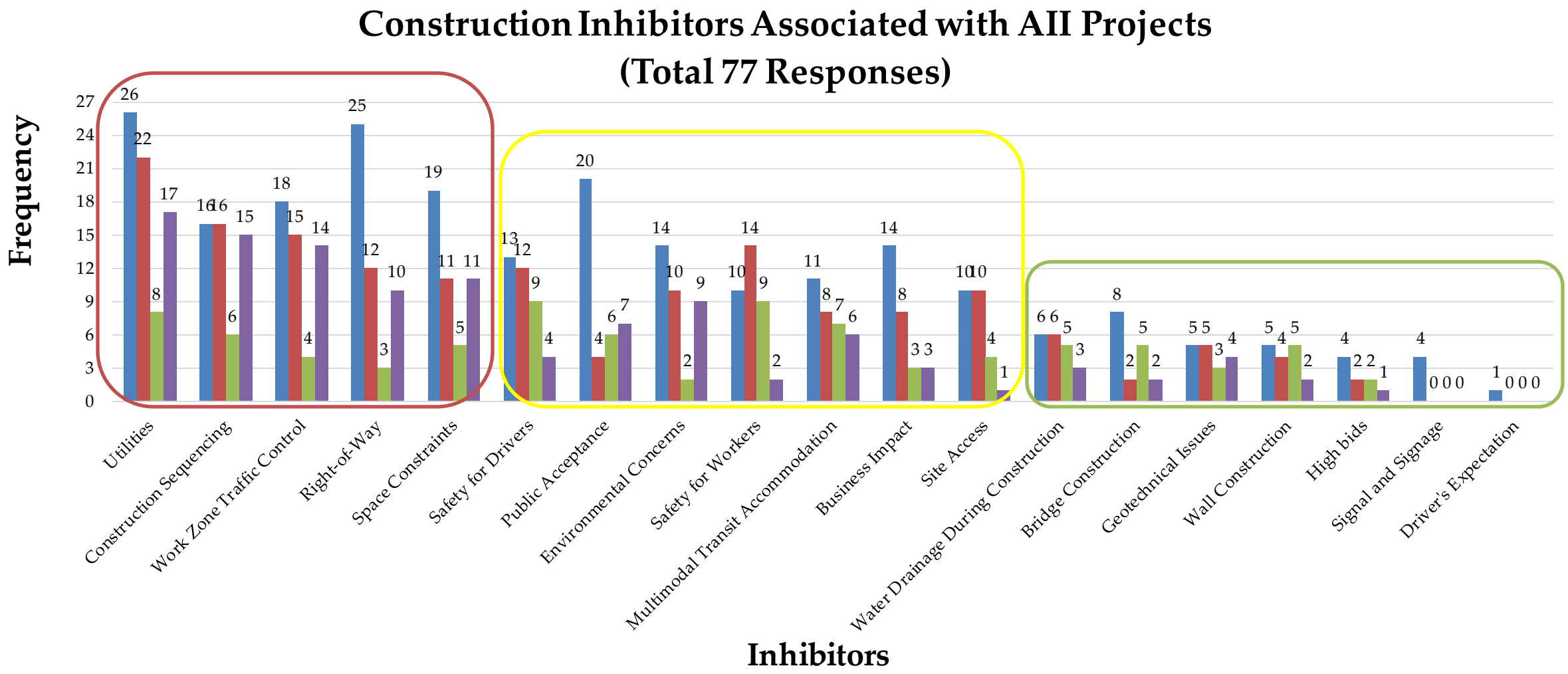
Field Study

- A total of three construction projects were monitored for 10 months

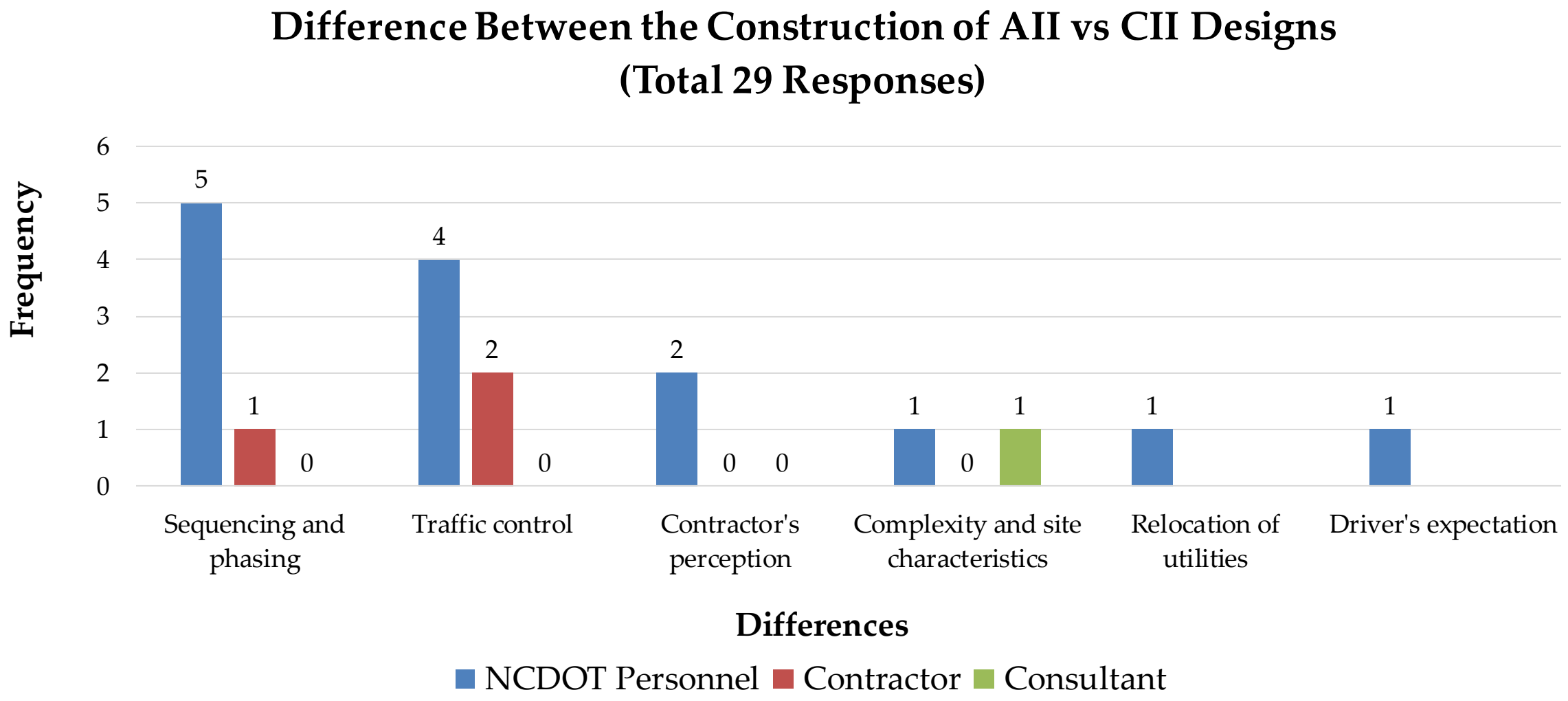
Findings

- Constructability factors
- AII vs CII
- Space constrained
- Business process

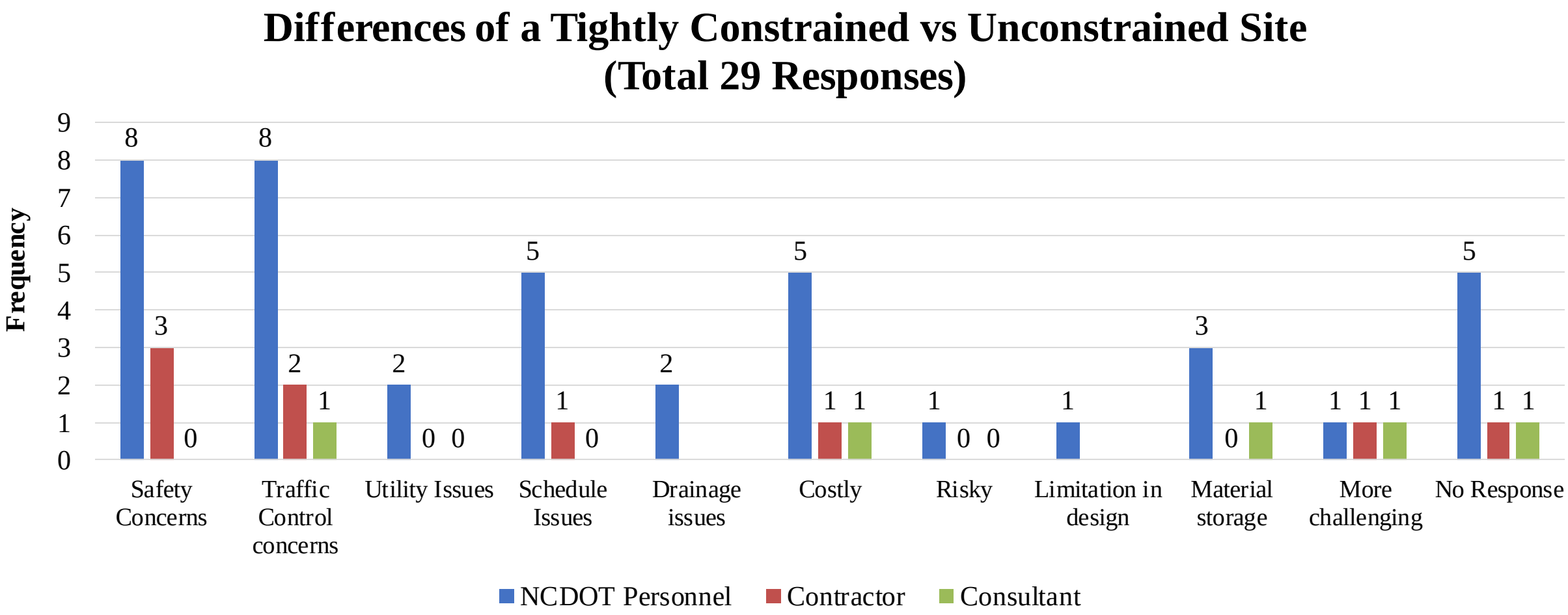
Interviews and Surveys



Interviews and Surveys

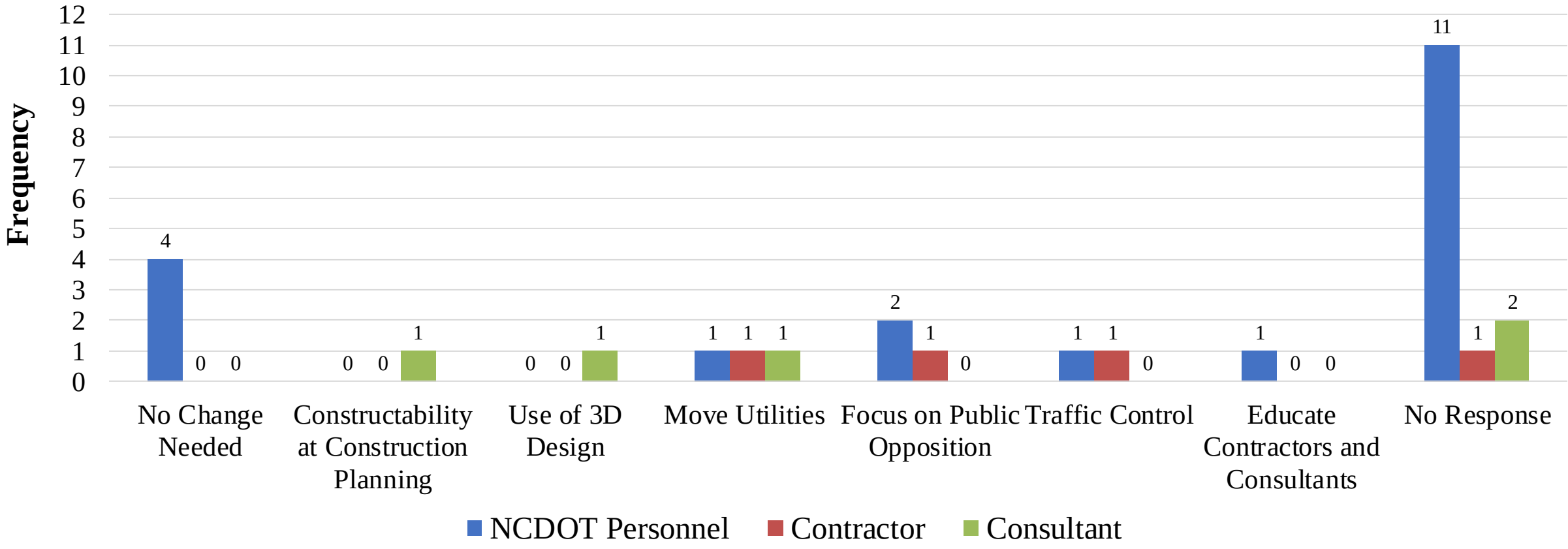


Interviews and Surveys



Interviews and Surveys

NCDOT Business/Construction Process Changes Needed for Improving the Construction and Design of AIIs (Total 29 Responses)



Main Findings from Interviews and Surveys

1. AIIs present signing problems during and after construction.

2. Contractors are willing to bid on AIIs even if they are unfamiliar designs.

3. Enhancers improve schedule performance and reduce the cost of projects.

4. Terminology (naming of AIIs) plays an important role in public acceptance.

Main Findings from Interviews and Surveys

5. There is a learning curve for constructing (construction personnel) and using (public) AIIs.

6. Move away from focusing on the constructability of AIIs and focus on how can we communicate the designs to the public to mitigate public opposition.

7. Staging makes a big difference and improves project performance.

Interviews and Surveys

Inhibitors identified for all AIIs design types and are based on stakeholder's opinion.

Inhibitors	Frequency (%)
Utilities	9%
Business Impact	9%
Public Acceptance	9%
Multimodal Traffic Accommodation	7%
Right of Way	7%

Frequency (%): # of inhibitors/ total # inhibitors reported by all respondents.
* Frequency of a total of 18 inhibitors identified by participants

NCDOT Field Study

Inhibitors identified based on observation on three Diverging Diamond Projects.

Inhibitors	Frequency (%)
Material Delivery	21%
Space Constraints	14%
Utilities	14%
Design Errors	7%
Design Specifications	7%

Frequency (%): Percent of all inhibitors identified in construction projects.
* Frequency of a total of 10 inhibitors observed over 10-month field studies

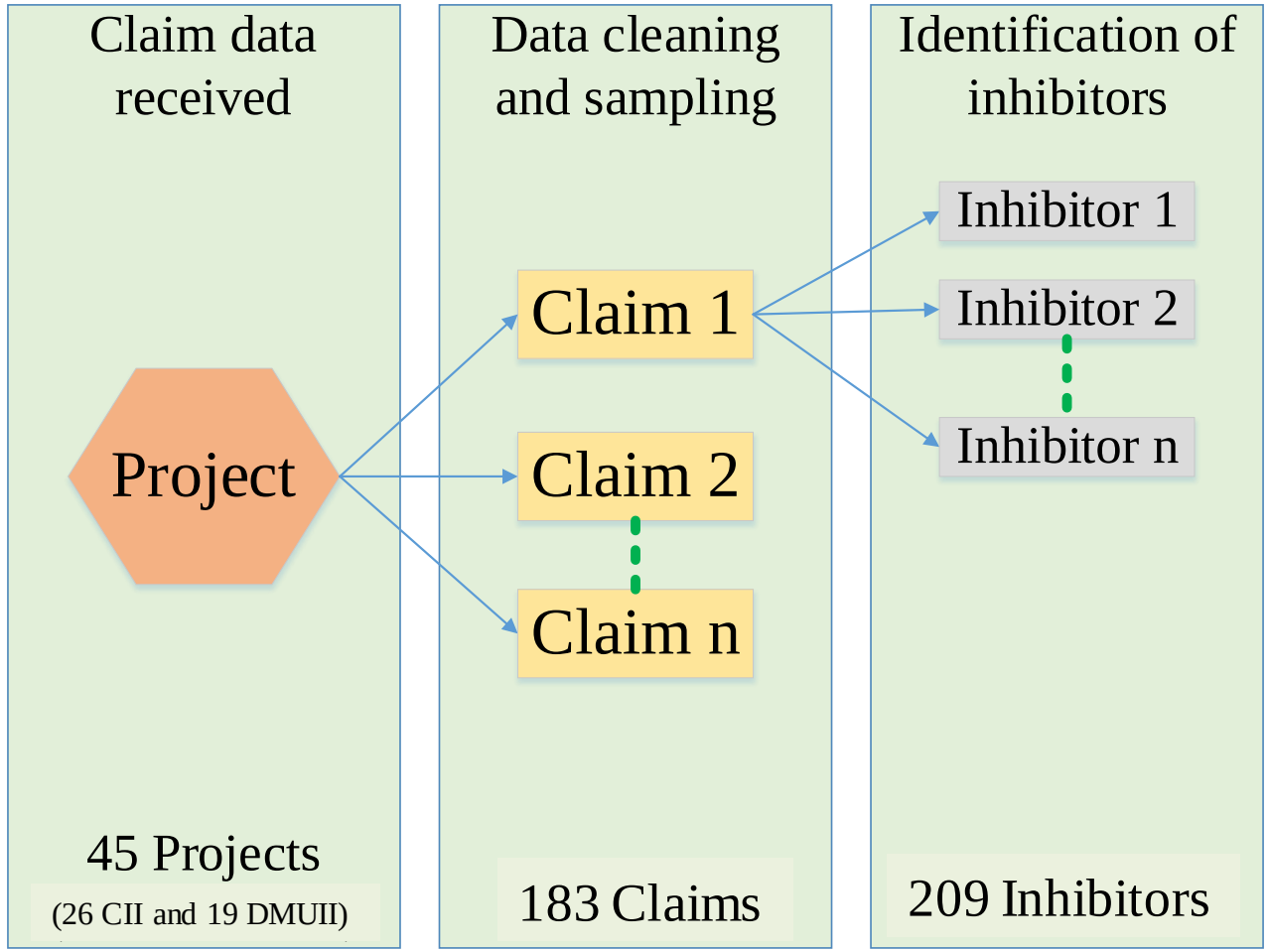
Claim Data

Claims

(Bills for unexpected work)

A request for more time or money to compensate for losses due to changes or additions.

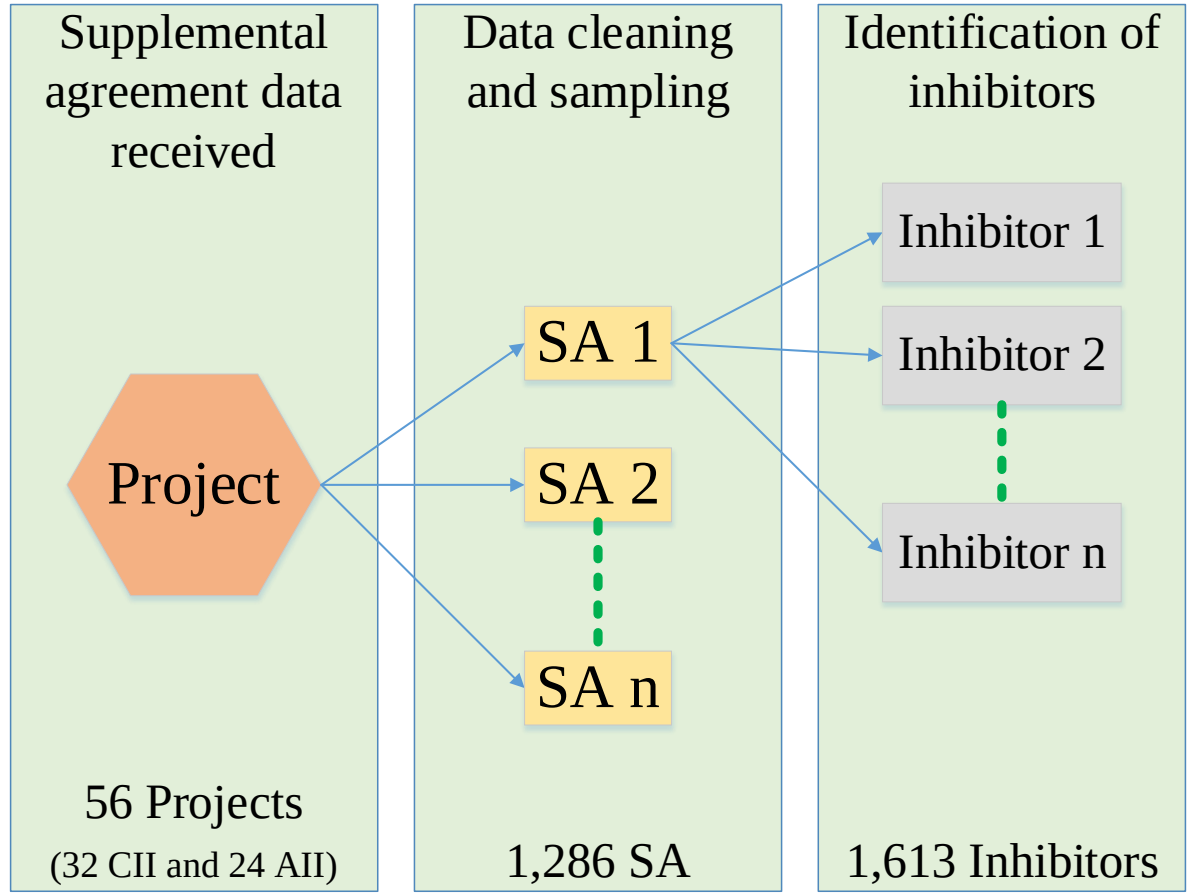
"Due to plan revisions causing additional earthwork, additional surveying, and delays from Hurricane Florence, it was agreed upon to provide 86 days to ICT 6 to facilitate negotiations of the release of claim dated 4-4-19."



Supplemental Agreement Data

Supplemental Agreement
(also known as a change order)

A request to amend the contract in terms of monetary compensation, time, or scope of work as necessary to satisfactorily complete additional construction work not initially contracted for.



Relevance of Inhibitors to AII Design Type

- Inhibitors cannot be generalized for all AIIs.
- Chi-Square test was performed to determine the relevance of inhibitors.
  - Results indicate a statistical significance (p-value < 0.05) relationship among all the AIIs evaluated.
  - Statistical significance indicates that the relationship between the inhibitors and AIIs is highly likely to have a meaningful rather than a random connection.

CFI
- Signals and signage
- Material estimate change
- Utilities
- Weather impact
- Contract changes

DDI
- Permit acquisition
- Material estimate change
- Safety for drivers
- Site access
- Traffic control

QR
- Contract changes
- Bridge construction
- Multimodal transit accommodations
- Contract errors
- Safety for public

RCI
- Contract changes
- Utilities
- Design errors
- Signals and signage
- Traffic control

TI
- Signals and signage
- Material estimate change
- Permit acquisition
- Utilities
- Environmental concerns

CII
- Utilities
- Material estimate change
- Contract changes
- Standards and specifications
- Design specifications

CFI: Continuous Flow Intersection **DDI:** Diverging Diamond Interchange **QR:** Quadrant Roadway Intersection
CI: Reduced Conflict Intersection **TI:** Turbine Interchange **CII:** Conventional Intersections or Interchanges

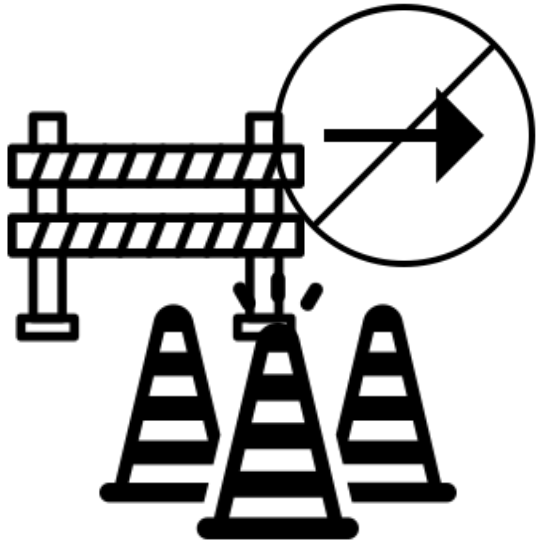
Conclusions

Findings indicate valuable insights into the inhibitors that affect projects.

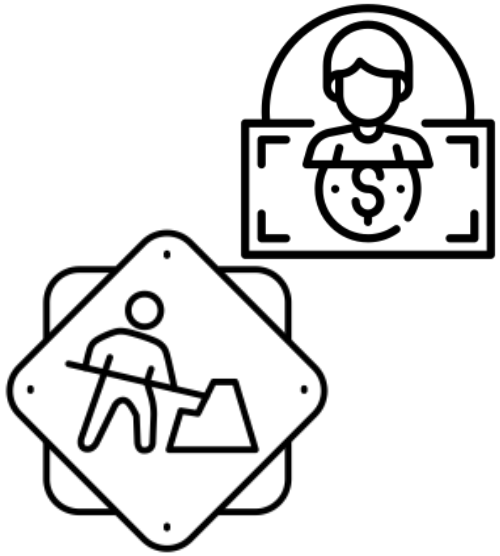
- Documenting and keeping track of inhibitors is important.
- Inhibitors affecting AIIs vary depending on the design type. Therefore, each design needs to assess its respective inhibitors.
- Utilities are one of the main inhibitors in projects, it is recommended to pay close attention to them.

Case Study: Evaluation of Roadway Congestion and Detours Due to Work Zone Traffic Control Measures

Travel Time Evaluation



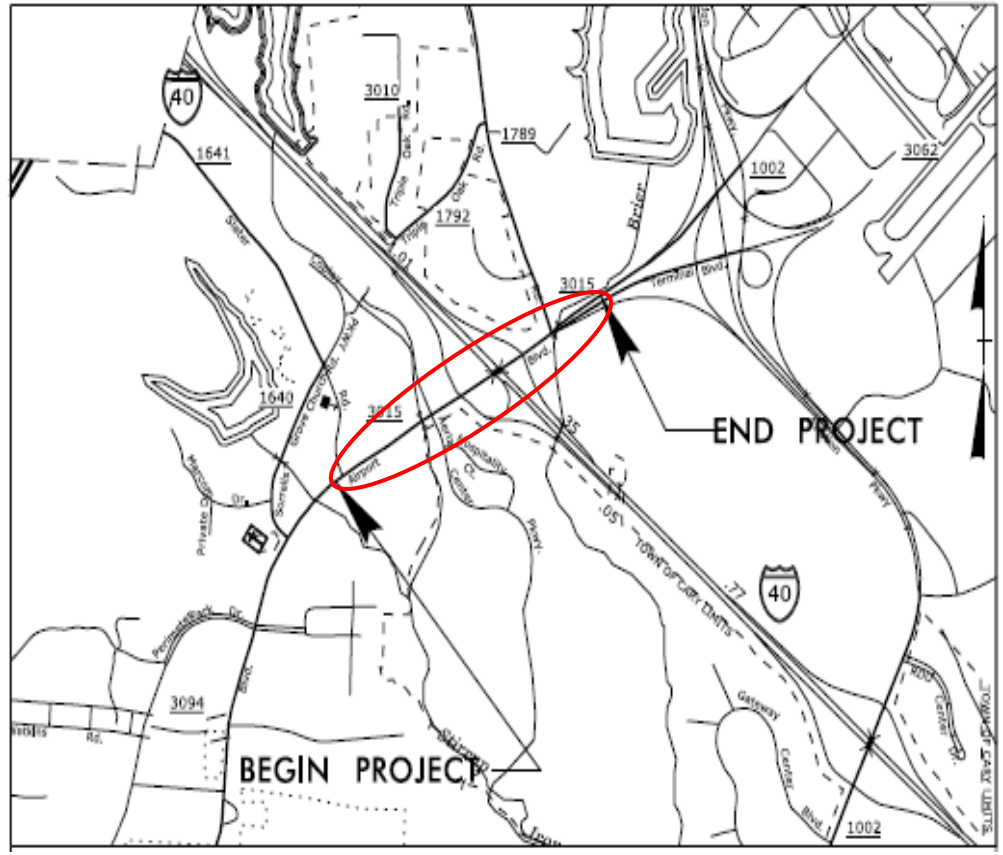
Congestion Evaluation



Road User Cost Evaluation

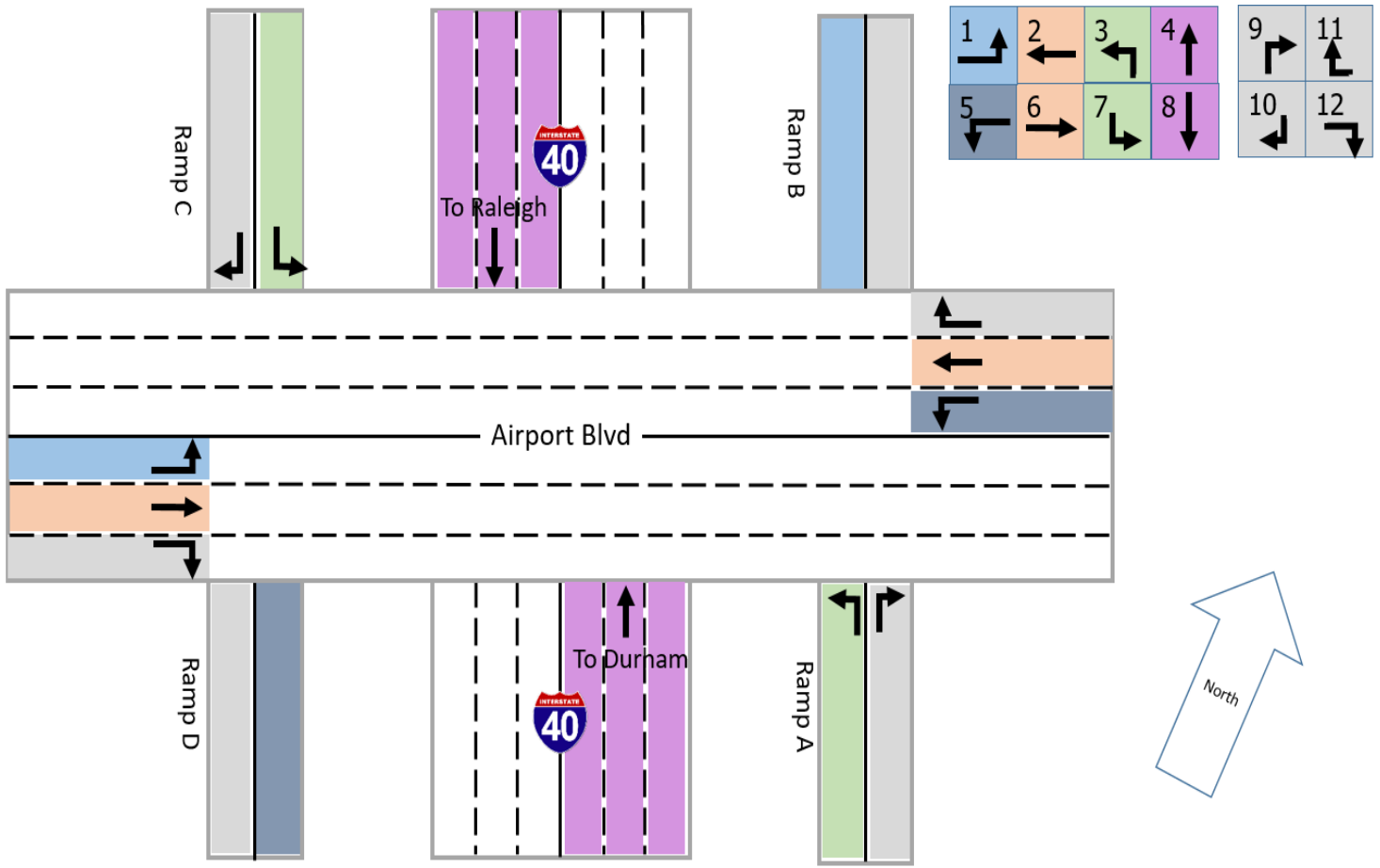
Site 1: I-5700 DDI (I-40 and Airport Blvd)

- **Project Started:** February 3, 2020.
- **Expected Completion:** February 11, 2024.
- **Ramp Closures:**
  - 105 days for ramps B and C.
  - 120 days for ramps A and D.
- **WZTC measure:** with detour.
- **Scope:** Grading, drainage, paving, signals, and structures work.
- **Project length:** 0.798 miles.

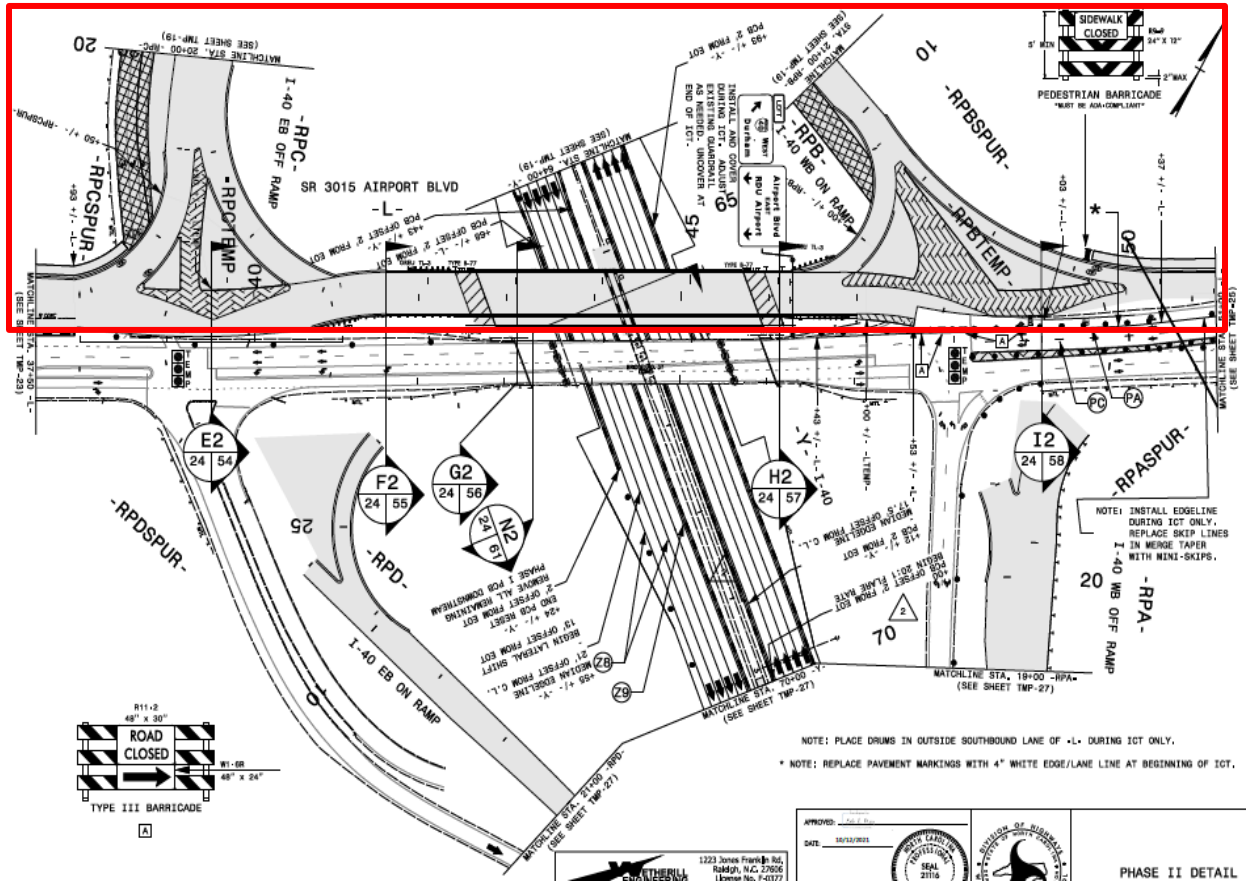


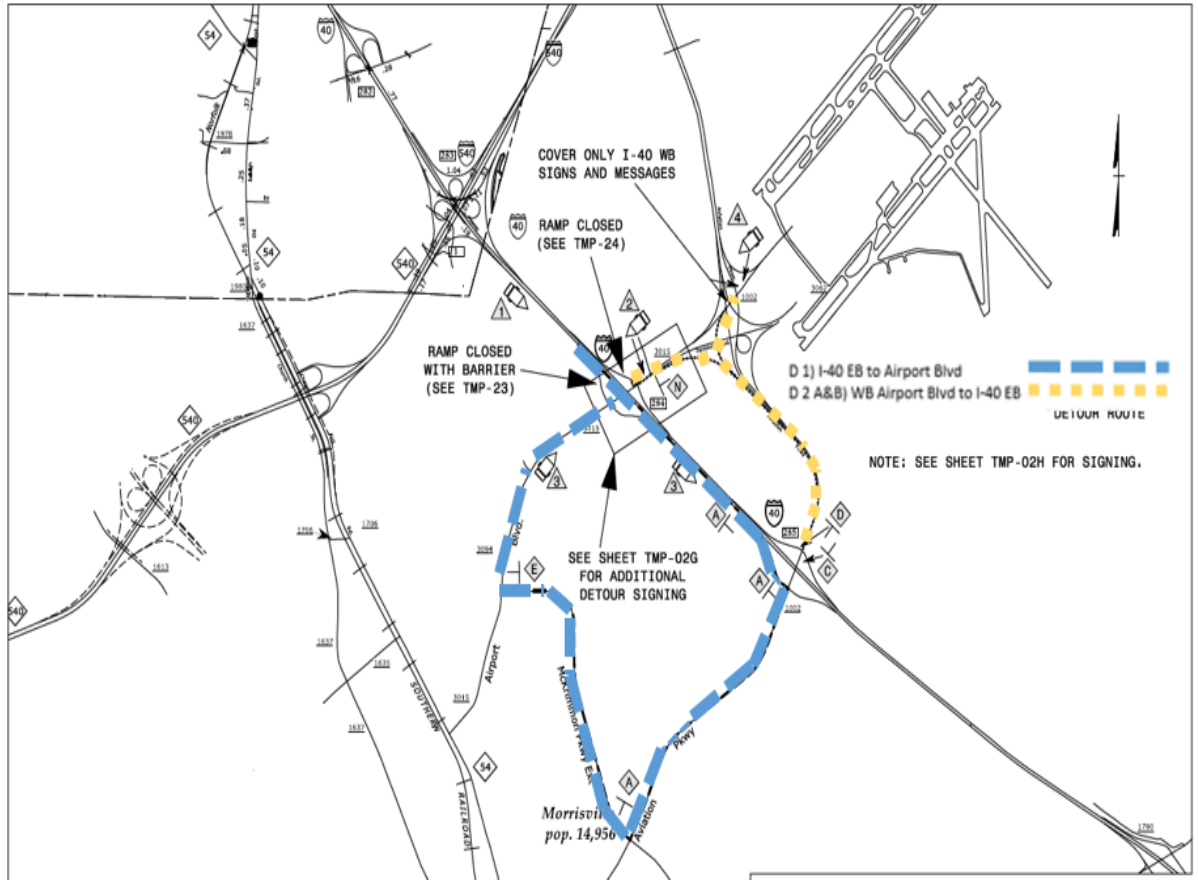
DDI: Diverging Diamond Interchange

Traffic Movement in I-5700 DDI Project



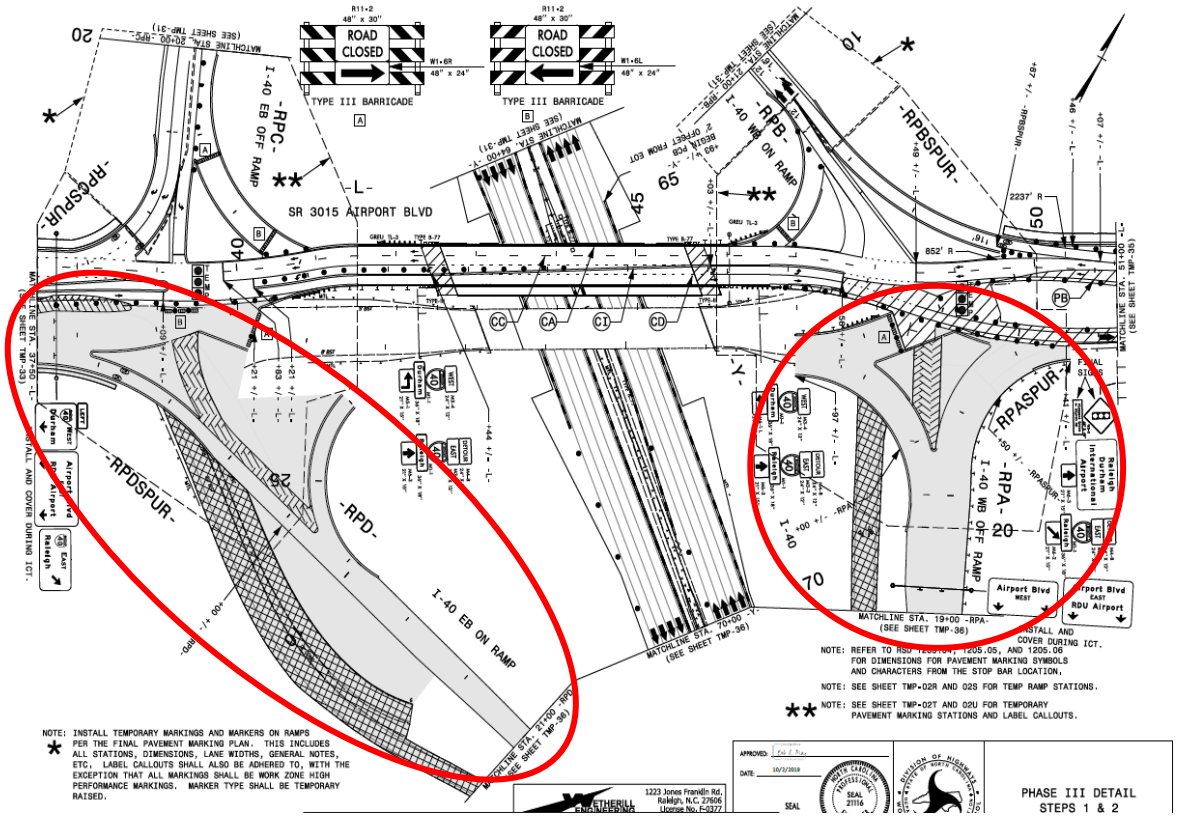
Phase II Closure of Ramps B and C and Detour Routes in I-5700 DDI Project

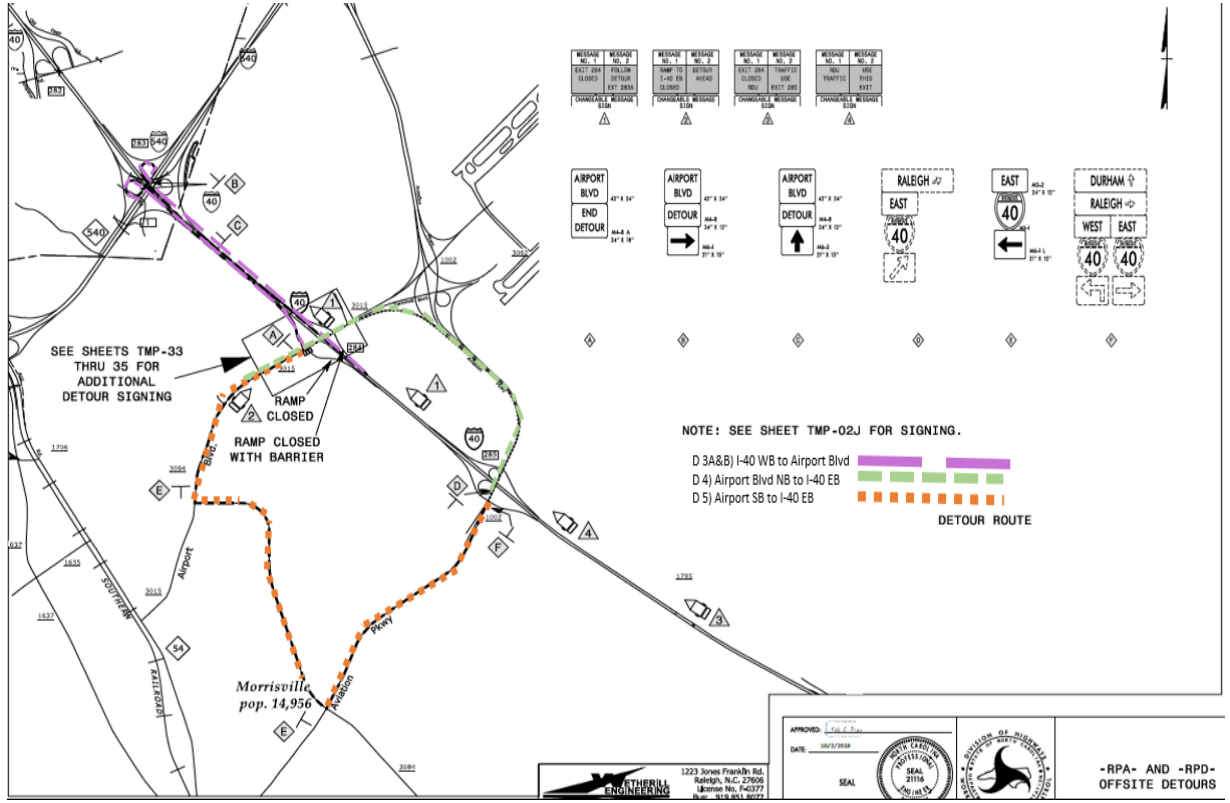




Phase III Closure of Ramps A and D and Detour Routes in I-5700 DDI Project

*Phase III will only be considered for **Road User Cost** calculations





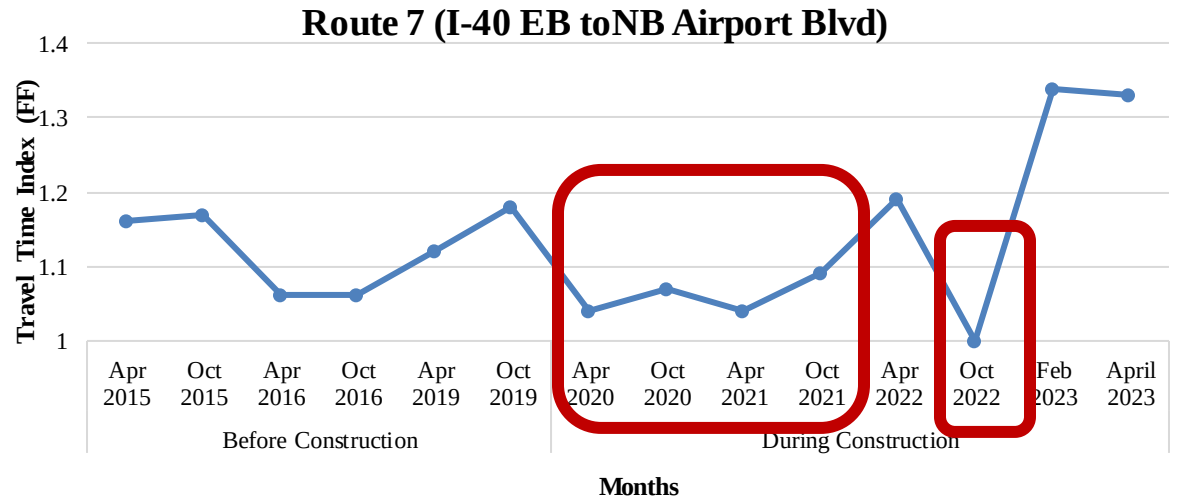
Evaluation of Travel Time Due to Detour Measures in I-5700 DDI Project

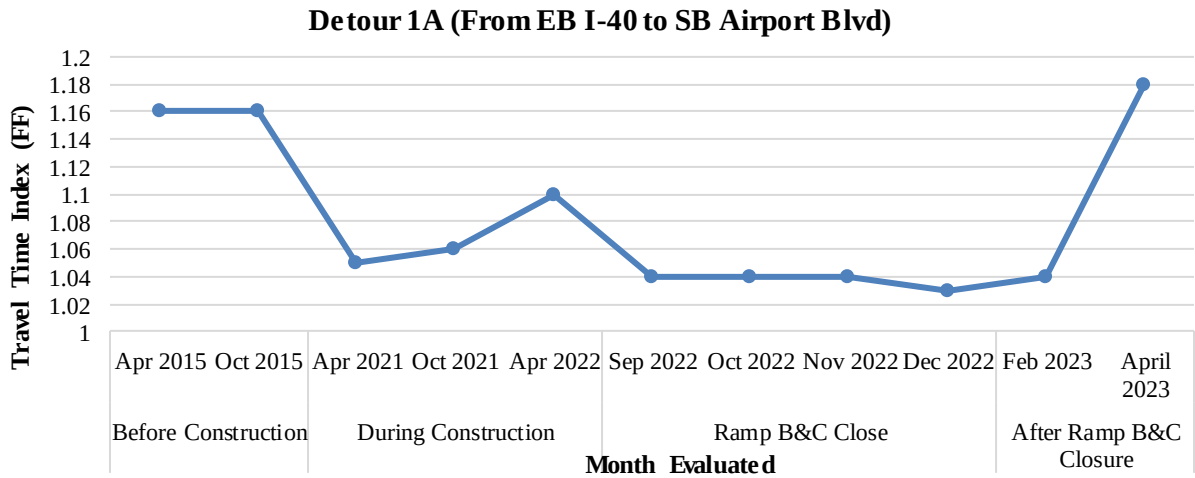
$$Travel\ Time = \frac{Distance(miles)}{Average\ Speed\ (mph)}$$

Route and Movement	Traffic Movement		Detour	Original Route Length (mile)	Detour Length (mile)	Additional Distance Travel due to Detour (mile)	Speed Limit (mile/hr.)		Travel Time (min/veh.)		Added Travel Time due to WZTC (min/veh.)
	Origen	Destination					Route	Detour	Route	Detour	
1	Airport Boulevard NB	I-40 WB	D2A	1.03	3.67	2.64	45	55	1.4	4.0	2.6
2	Airport Boulevard SB	Airport Boulevard SB	No Detour	0.38	No Detour	0	45	55	0.5	No Detour	No Detour
3	I-40 WB	Airport Boulevard SB	D3A	0.54	4.6	4.06	45	55	0.7	5.0	4.3
4	I-40 WB	I-40 WB	No Detour	1.24	No Detour	0	65	55	1.1	No Detour	No Detour
5	Airport Boulevard SB	I-40 EB	D5	1.92	4.65	2.73	45	55	2.6	5.1	2.5
6	Airport Boulevard NB	Airport Boulevard NB	No Detour	0.36	No Detour	0	45	55	0.5	No Detour	No Detour
7	I-40 EB	Airport Boulevard NB	D1	0.87	6.08	5.21	45	55	1.2	6.6	5.5
8	I-40 EB	I-40 EB	No Detour	0.95	No Detour	0	65	55	0.9	No Detour	No Detour
9	I-40 WB	Airport Boulevard NB	D3B	0.4	5.24	4.84	45	55	0.5	5.7	5.2
10	I-40 EB	Airport Boulevard SB	D1	0.59	5.75	5.16	45	55	0.8	6.3	5.5
11	Airport Boulevard SB	I-40 WB	D2B	1.54	3.4	1.86	45	55	2.1	3.7	1.7
12	Airport Boulevard NB	I-40 EB	D4	1.68	4.71	3.03	45	55	2.2	5.1	2.9

Congestion Analysis: Monthly Travel Time Index Values for Routes in I-5700 DDI Project

- The Travel Time Index (TTI)
  - Allows congestion levels to be evaluated.
  - Traffic performance to be monitored.
  - The impact of WZTC measures to be assessed.
- TTI = 1 indicates no congestion or delay.
- TTI > 1 indicates higher levels of congestion and longer travel times.
  - For example, a TTI = 1.2 indicates that travel time under free-flow conditions takes 20% longer than the expected.





RUC in I-5700 DDI Project

Road User Cost (RUC) Model quantifies work zone delay, detour delay, and vehicle operating cost.

The input data for RUC is shown below.

Road User Cost Data Input

Route	AADT	AADT Cars	AADT Trucks	Length (mile)			Additional Distance Travel due to Detour (mile)	Speed Limit (mile/hr.)			% Vehicles Using Detour
				Route	Work Zone	Detour		Route	Work Zone	Detour	
1	4,050	3,858	181	1.03	0.2	3.67	2.64	45	45	55	100%
2	13,625	12,979	610	0.38	0.2	0	0	45	45	55	0
3	3,600	3,429	161	0.54	0.2	4.6	4.06	45	45	55	100%
5	3,450	3,287	154	1.92	0.2	4.65	2.73	45	45	55	100%
6	13,625	12,979	610	0.36	0.2	0	0	45	45	55	0
7	3,900	3,715	174	0.87	0.2	6.08	5.21	45	45	55	100%
9	3,600	3,429	161	0.4	0.3	5.24	4.84	45	45	55	100%
10	3,900	3,715	174	0.59	0.3	5.75	5.16	45	45	55	100%
11	4,050	3,858	181	1.54	0.1	3.4	1.86	45	45	55	100%
12	3,450	3,287	154	1.68	0.1	4.71	3.03	45	45	55	100%

RUC in I-5700 DDI Project

Detour Travel Delay Cost

$$Travel\ Time = \frac{Distance(miles)}{Average\ Speed\ (mph)}$$

$$Travel\ Delay\ Cost = Delay\ time\ (hrs) * Hourly\ Dollar\ Value\ of\ Delay$$

The RUC model enable us to calculate the detour travel delay cost ($/vehicle)

Route	Value of Time ($/hr.)		Travel Time along Route (min)	Travel Time along Detour Route (min)	Detour Delay Time (min)	Detour Delay Cost per Vehicle		Total Detour Delay Cost ($/vehicle)	
	Car	Truck				Cars	Trucks	Cars	Trucks
1	$12.50	$50.00	1.37	4.00	2.63	$0.55	$2.19	$2,114.16	$397.15
2	$12.50	$50.00	0.51	0.00	0.00	$0.00	$0.00	$0.00	$0.00
3	$12.50	$50.00	0.72	5.02	4.30	$0.90	$3.58	$3,070.89	$576.88
5	$12.50	$50.00	2.56	5.07	2.51	$0.52	$2.09	$1,720.45	$323.19

Road User Cost in I-5700 DDI Project

Additional Vehicle Operating Costs

$$Vehicle\ Operating\ Cost\ (VOC) = Unit\ Cost\ per\ Mile\ * Miles\ Traveled\ per\ Vehicle * Number\ of\ Vehicles$$

Route	Vehicle Operating Costs ($/mile)		Additional Miles due to detour (veh-miles)		Total Additional Vehicle Operating Costs	
	Car	Truck	Car	Truck	Car	Truck
1	$0.20	$0.50	10185	478	$2,037.07	$239.17
2	$0.20	$0.50	0	0	$0.00	$0.00
3	$0.20	$0.50	13923	654	$2,784.69	$326.95
5	$0.20	$0.50	8972	421	$1,794.44	$210.68

Road User Cost in I-5700 DDI Project

Total Road User Costs

$$Total\ Project\ Road\ User\ Cost\ (RUC) = (Delay\ Cost\ * Total\ days) + (Operating\ Cost * Total\ Days)$$

WZTC Ramp Closures	Detour Travel Delay Cost	Additional Vehicle Operating Costs	Total RUC
Ramps A&D (105 days)	$1,306,963	$1,160,425	$2,467,388
Ramps B&C (120 days)	$1,700,122	$1,498,797	$3,198,918
Total			**$5,666,306.43**

Site 2: U-5806 CI

(Concord Mills Blvd and Entrance #1 at Kings Grant Pavilion)

- **Project Started:** August 13, 2018.
- **Completion:** August 18, 2022.
  - Project lasted 1,571 days.
- **Night Lane Closures:**
  - 7:00 PM to 6:00 AM.
- **WZTC measure:** No detour. Lane Closure
- **Scope:** Grading, drainage, paving, signals, and structures work.
- **Project length:** 0.434 miles.

CI: Conventional Intersection

Road User Cost in U-5806 CI Project

Road User Cost Data Input

- Night Lane Closures: 7:00 PM to 6:00 AM.

Route	AADT	Adjusted AADT	AADT Cars	AADT Trucks	Length (mile)			Additional Distance Travel due to Detour (mile)	Speed Limit (mile/hr.)		Vehicles Using Detour
					Route	Work Zone	Detour		Route	Work Zone	
2	17,125	3,117	2,969	139	0.55	0.55	0	0	45	35	0%
6	17,125	3,117	2,969	139	0.55	0.55	0	0	45	35	0%

Hour	Hourly-AADT	HDF
12:00 - 1:00 AM	127	0.74%
1:00 - 2:00 AM	80	0.47%
2:00 - 3:00 AM	70	0.41%
3:00 - 4:00 AM	86	0.50%
4:00 - 5:00 AM	144	0.84%
5:00 - 6:00 AM	377	2.20%
6:00 - 7:00 AM	1,029	6.01%
7:00 - 8:00 AM	1,572	9.18%
8:00 - 9:00 AM	1,413	8.25%
9:00 - 10:00 AM	1,041	6.08%
10:00 - 11:00 AM	885	5.17%
11:00 - 12:00 AM	891	5.20%
12:00 - 1:00 PM	921	5.38%
1:00 - 2:00 PM	944	5.51%
2:00 - 3:00 PM	971	5.67%
3:00 - 4:00 PM	1,041	6.08%
4:00 - 5:00 PM	1,132	6.61%
5:00 - 6:00 PM	1,211	7.07%
6:00 - 7:00 PM	957	5.59%
7:00 - 8:00 PM	676	3.95%
8:00 - 9:00 PM	531	3.10%
9:00 - 10:00 PM	450	2.63%
10:00 - 11:00 PM	341	1.99%
11:00 - 12:00 PM	235	1.37%
Total	**17125**	**100%**
Adjusted AADT (7:00 pm to 6:00 am)		**3,116.75**

*Values to calculate adjusted AADT are highlighted in grey

Road User Cost in U-5806 CI Project

Work Zone Delay Cost

Route	Value of Time ($/hr.)		Travel Time along Route (min)	Travel Time at Work Zone Speed (min)	Work Zone Delay Time (min/veh.)	Work Zone Delay Cost per Vehicle		Total Work Zone Delay Cost	
	Car	Truck				Car	Truck	Car	Truck
2	$12.75	$50.00	0.73	0.94	0.21	$0.04	$0.17	$132.19	$24.35
6	$12.75	$50.00	0.73	0.94	0.21	$0.04	$0.17	$132.19	$24.35

Total Road User Costs

WZTC Time	Work Zone Travel Delay Cost ($/day)	Additional Vehicle Operating Costs ($/day)	Total RUC
1,571 Days	$313.08	$0	**$491,850**

Conclusions

- The impact on WZTC measure is different based on which control measure was applied.
- Adopting detour analysis will aid NCDOT in selecting the most efficient and cost-effective solutions for WZTC.
- These findings further support the notion that, despite the unfamiliarity surrounding AII projects, their construction performance is not exacerbated compared to CIIs.

Acknowledgements

- Research Team: Drs. Nagui Rouphail, Kevin Han, and Rudi Seracino
- Clare Fullerton and Stephanie Bolyard former NCDOT Employees
- Benard Chola, NCDOT Chief Engineer's Office
- Natalia Arbelaez, Liam Shannon, Robert Bullock, and Jacob Crews, NCDOT Field Engineers and Resident Engineers

NC STATE

Thank You

Contact us at:

William Rasdorf, Ph.D.
rasdorf@ncsu.edu
Phone: (919) 515-7637

Minerva Bonilla, Ph.D.
mbonilla@tamu.edu
Phone: (979) 458-7746