

Transportation Learning Network

A partnership with
MDT, NDDOT, SDDOT, WYDOT and the
Mountain-Plains Consortium Universities



Holly Lloyd

Utah State University Graduate Researcher

Comprehensive Safety Analysis of Diverging Diamond Interchanges

Tuesday, January 16, 2018 – 10:00 AM – 11:00 AM CT (9:00 AM – 10:00 AM MT)

Thank you to
our partners:



NDSU

UPPER GREAT PLAINS TRANSPORTATION INSTITUTE
TRANSPORTATION LEARNING NETWORK

Comprehensive Safety Analysis of Diverging Diamond Interchanges

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Comprehensive Safety Analysis of Diverging Diamond Interchanges

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- ▶ **Diverging Diamond Interchange**
- ▶ **Previous Safety Studies**
- ▶ **Study Site Selection & Data Collection**
- ▶ **Safety Performance Function Calibration**
- ▶ **Empirical Bayes Before-After Methodology**
- ▶ **Discussion of Results**

DIVERGING DIAMOND
INTERCHANGE
(DDI)

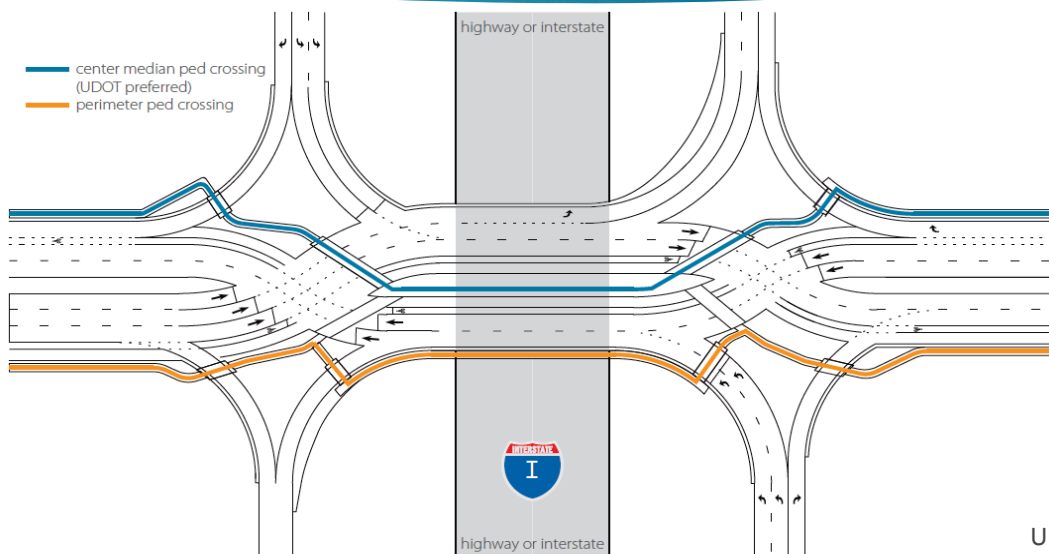
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WHAT?
WHERE?
WHY?
HOW?

DDI – What?



Pedestrian/Bicyclist Pathway Options



DDI – Where?

7

First in US

Missouri
2009

First in
Utah

American
Fork 2010

Total in US

89

Total in
Utah

8

DDIs in TLN & MPC

8

Colorado

3

Montana

0

North
Dakota

0

South
Dakota

0

Wyoming

1

DDI – Why?



Improve Flow & Capacity



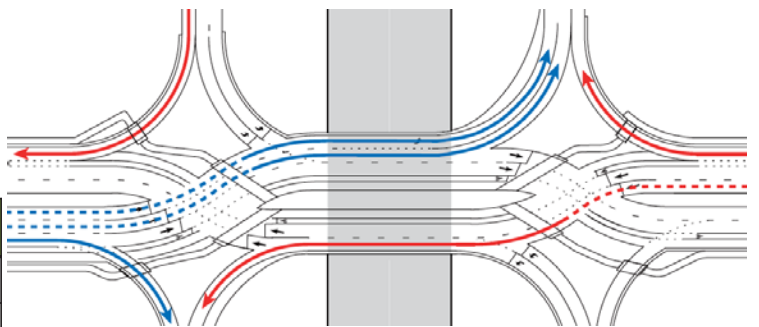
Accommodate Unbalanced Flow



Improve Safety

DDI – How?

- ▶ Accommodate left-turning movements
- ▶ Eliminate left-turn bay & signal phase
- ▶ Decrease speed limit
- ▶ Decrease conflict points



Conflict Points		
Type	Standard Diamond	Diverging Diamond
Diverging	8	6
Merging	8	6
Crossing	10	2
Total	26	14

PREVIOUS DDI SAFETY STUDIES

Before-After Study Methodologies

- ▶ Naïve
 - ▶ Observed crashes in the before period = Expected crashes in the after period
 - ▶ Crash factors change over time and cannot be assumed consistent
- ▶ Comparison Group
 - ▶ Uses a ratio of observed crashes in the before and after periods at the comparison group to adjust the observed crashes in the before period at the treatment site
 - ▶
$$N_{exp-a-t} = \frac{N_{obs-a-u}}{N_{obs-b-u}} \times N_{obs-b-t}$$
- ▶ Empirical Bayes
 - ▶ Accounts for changes in traits of the individual drivers and the study site
 - ▶ Use of the reference group counteracts the regression-to-the-mean bias

Previous Safety Studies Performed for the DDI

Year of Report	Author	Location	Before Data (Years)	After Data (Years)	Study Method	Results	Source
2010	FHWA	VISSIM Simulation	N/A	N/A	Naïve Before-After	Positive	FHWA 2010
2010	MoDOT	Springfield, MO	5	1	Naïve Before-After	Decrease in Crashes	MoDOT 2010
2010	AASHTO	Lexington, KY	4	2	Naïve Before-After	Mixed; Some decrease, some increase within crash types	AASHTO 2010
Unknown	FHWA/ NYSDOT	Rochester, NY	3	0.667	Naïve Before-After	Mixed; Some decrease, some increase within crash types	FHWA 2014, NYSDOT
2015	MoDOT	Missouri	2.9-4.25	.83-4.25	Naïve, Comparison Group, Empirical Bayes	All Positive	MoDOT 2015

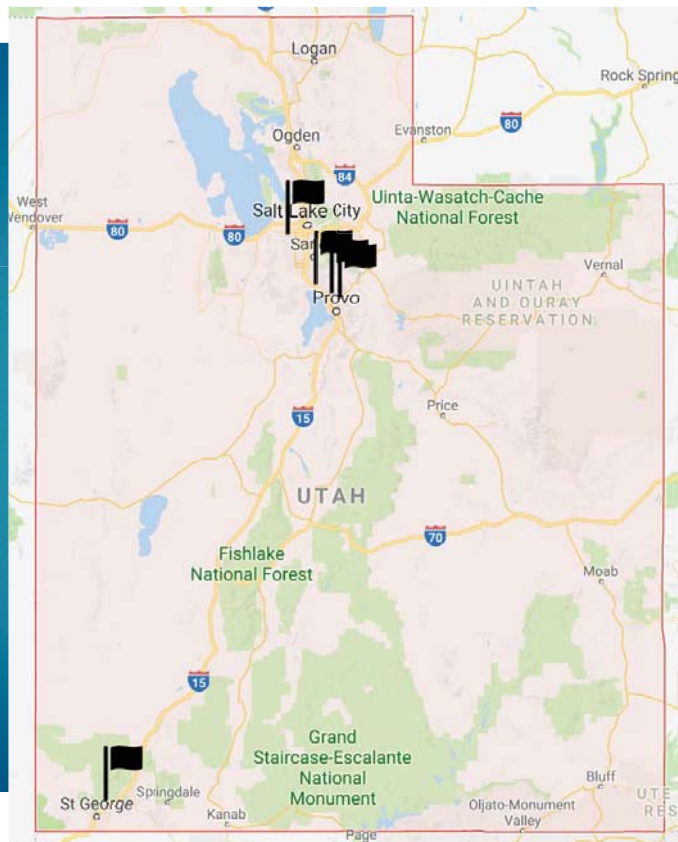
STUDY SITE SELECTION & DATA COLLECTION

Study Site Selection

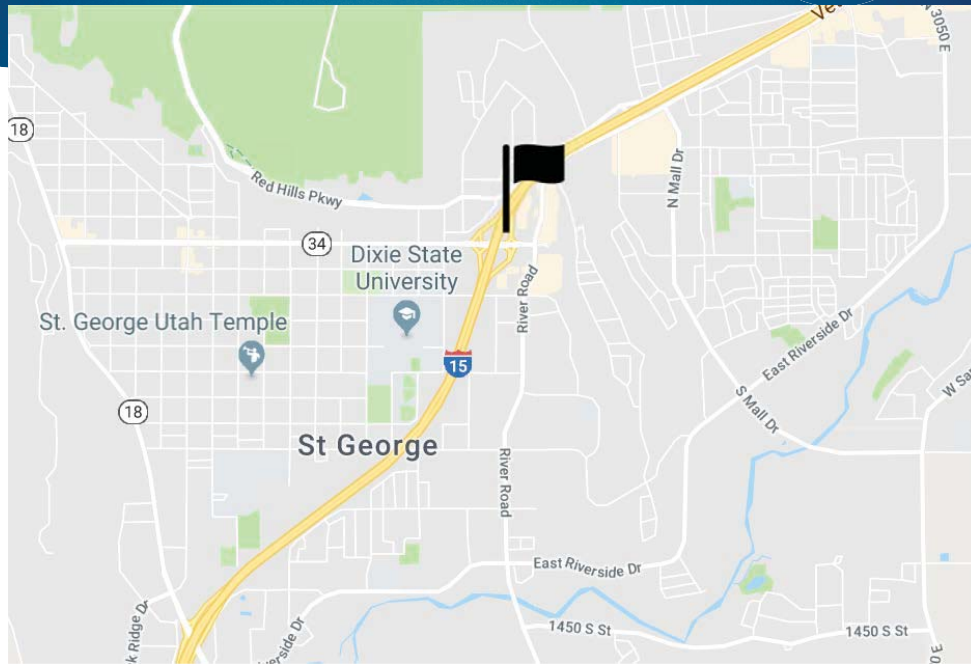
- ▶ Limiting factor: Available before & after data
 - ▶ Some DDIs were constructed too recently to provide an adequate number of years of data in the after period
- ▶ Selected study sites include:

Exit #	Interchange Location	City	Year Implemented	Before Years	After Years
278	I-15 & Main Street	American Fork	August 2010	3	4
284	I-15 & Timpanogos Hwy	Highland	August 2011	4	3
13	SR-201 & Bangerter Hwy	West Valley	October 2011	4	3
276	I-15 & 500 East	American Fork	November 2011	4	3
8	I-15 & St. George Blvd	St. George	November 2013	6	1

Selected Study Sites



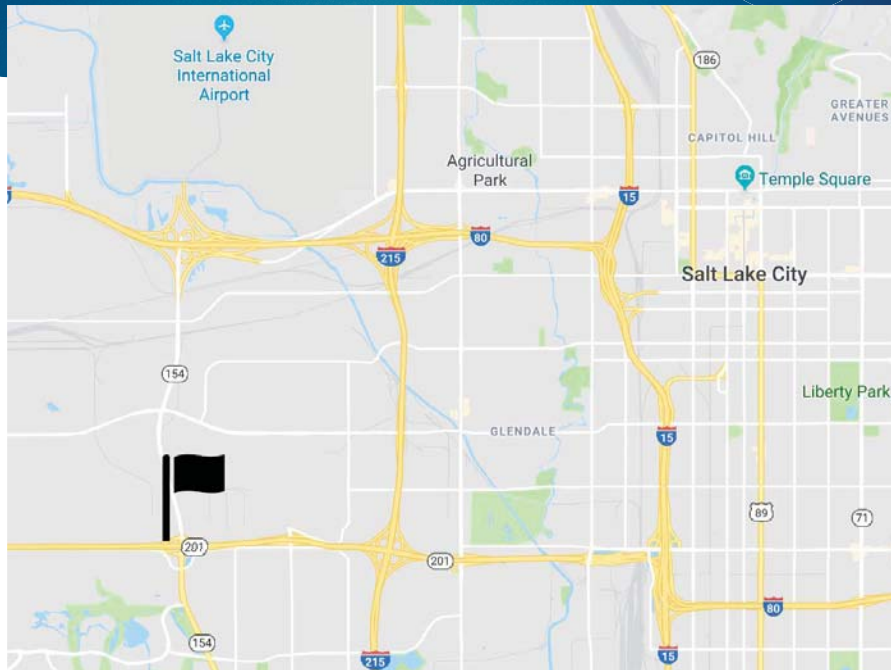
Exit 8 St. George Blvd



Exit 8 St. George Blvd



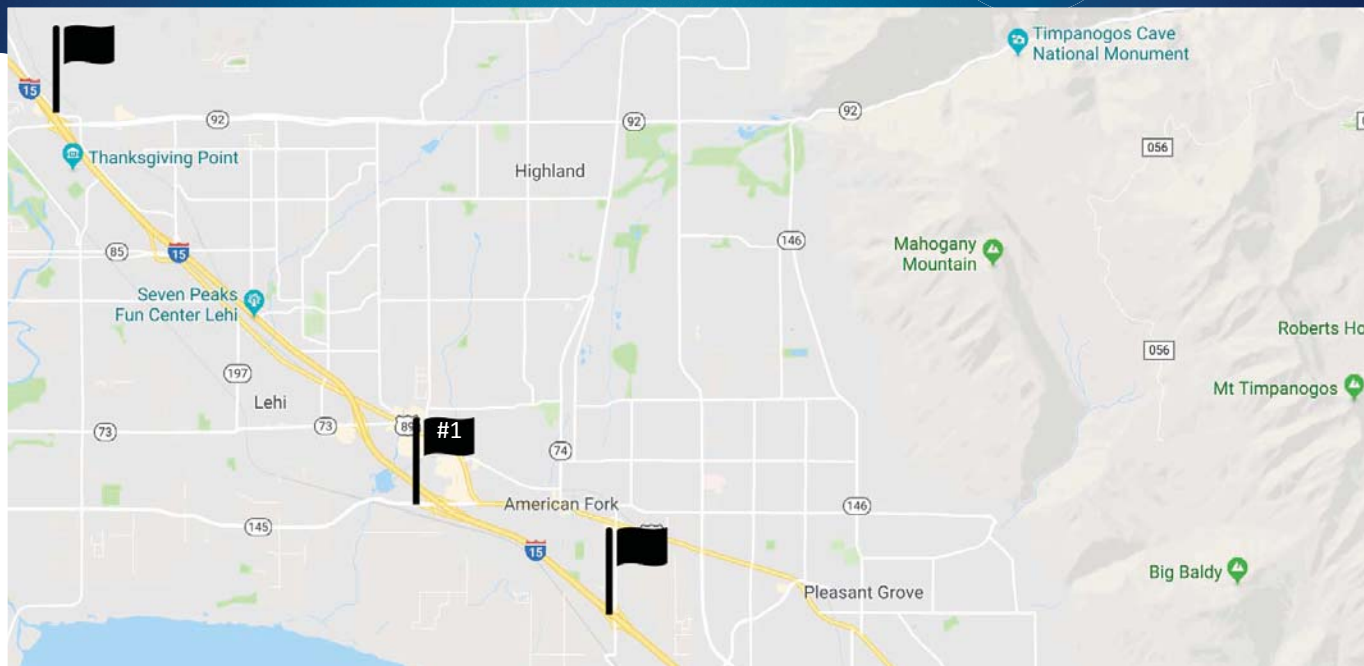
Exit 13 SR 201 & Bangerter Highway



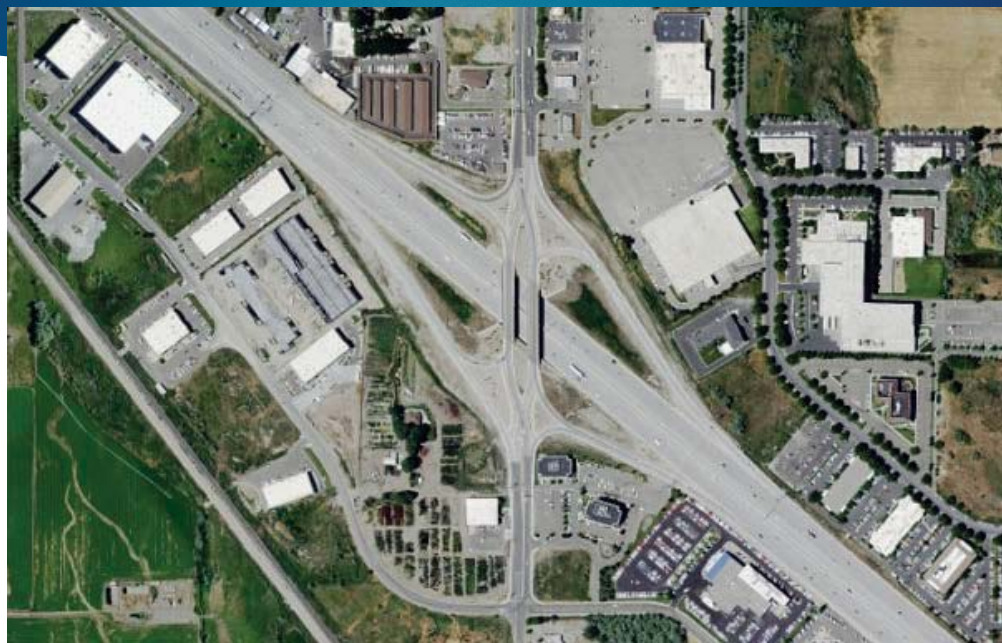
Exit 13 SR 201 & Bangerter Highway



Exits 276, 278 & 284



Exit 276 500 East in American Fork



Exit 278 Main Street in American Fork



Exit 284 Timpanogos Highway

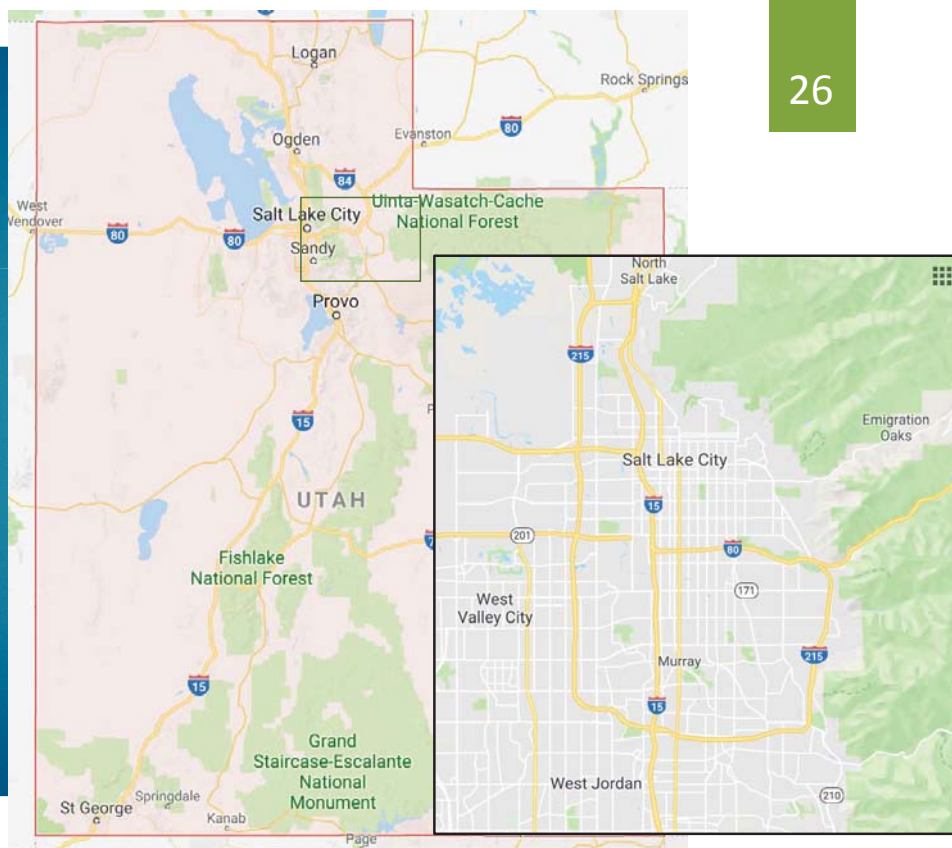


Comparison Group Selection

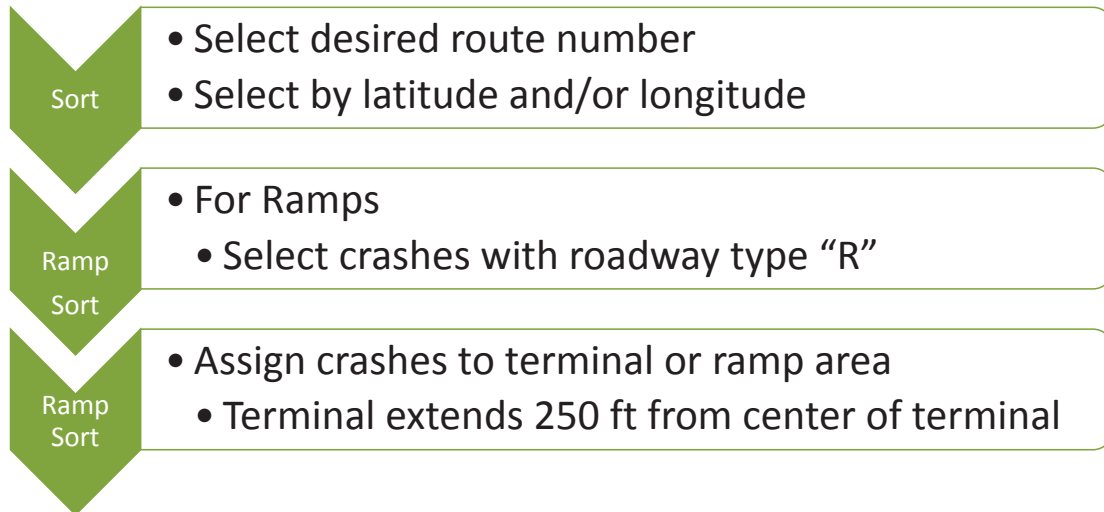
- ▶ Urban diamond interchanges along Utah freeways
 - ▶ I-15
 - ▶ I-80
 - ▶ I-215
 - ▶ SR-201



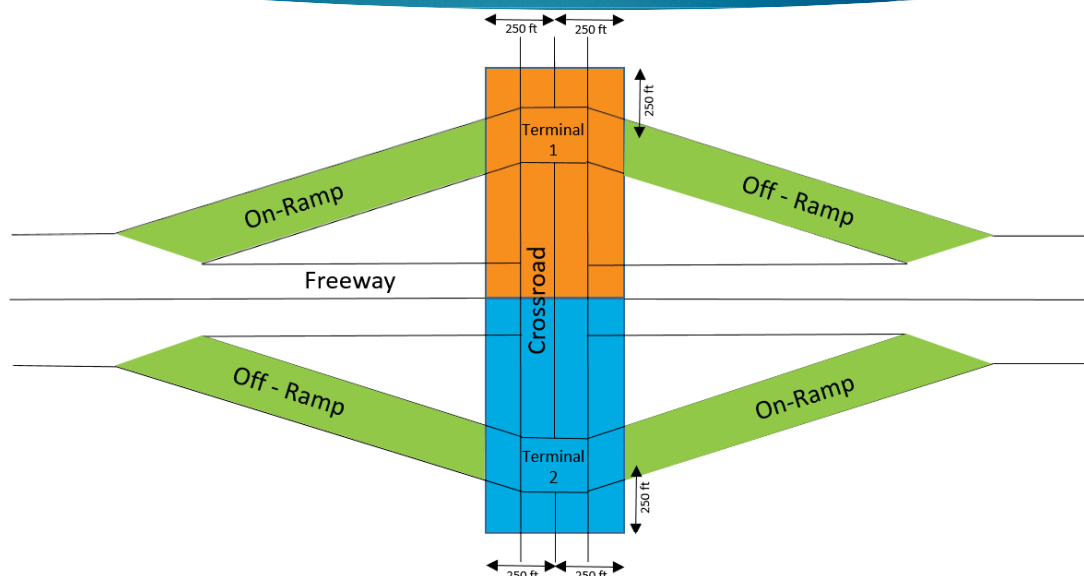
Comparison Group Site Locations



Data Collection



Data Selection Areas



Safety Performance Function (SPF)

Multiple Sources

Highway
Safety
Manual
(HSM)

FHWA
Interchange
Safety Analysis
Tool (ISAT)

Private
Studies

Base Functions

Regression
based on
selected crash
data

Must be
Calibrated

HSM & ISAT
provide
calibration
methods and
parameters

SPF Calibration Process

- Crash data is random and generally overdispersed
- Poisson regression can't handle overdispersed data

Negative
Binomial
Regression

Estimate SPF
Parameters

- HSM & ISAT base SPFs
- Use a comparison group of urban diamond interchanges for regression

Utah
Specific
SPFs

Selected SPFs

► HSM

$$\text{► } N_{HSM \text{ ramp}} = L \times \exp(a + b \times \ln[c \times AADT_{ramp}] + d \times [c \times AADT_{ramp}])$$

$$\text{► } N_{HSM \text{ terminal}} = \exp[a + b \times \ln(c \times AADT_{crossroad}) + d \times \ln(c \times AADT_{exit} + c \times AADT_{entrance})]$$

► ISAT

$$\text{► } N_{ISAT \text{ ramp}} = e^a \times AADT_{ramp}^b \times RL^e$$

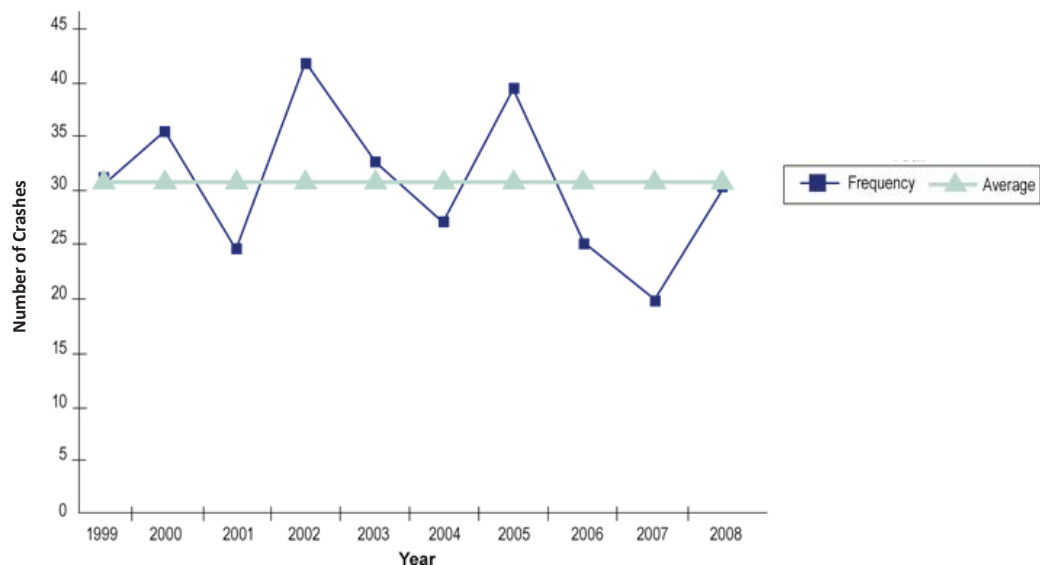
$$\text{► } N_{ISAT \text{ terminal}} = e^a \times AADT_{crossroad}^b \times AADT_{exit}^c$$

EMPIRICAL BAYES BEFORE-AFTER METHODOLOGY

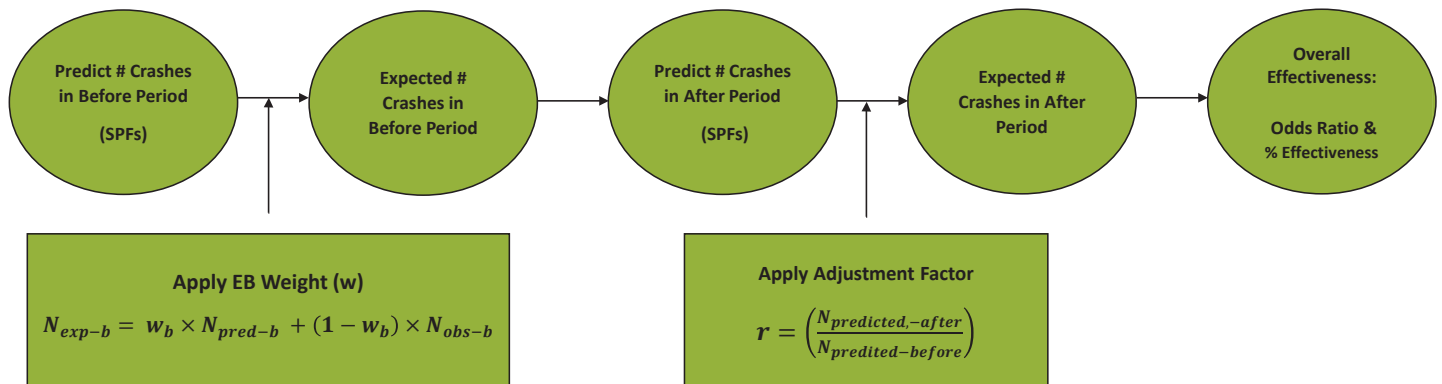
Empirical Bayes (EB)

- ▶ Accounts for changes in AADT, weather patterns, geometric road characteristics, etc. from before to after period
- ▶ Accounts for Regression-to-the-Mean Bias by incorporating crash information from other similar sites into the evaluation.

Regression-to-the-Mean Bias



EB Process



Detailed EB Equations

- ▶ $w_b = \frac{1}{1+k \sum N_{pred-b}}$
- ▶ $N_{exp-b} = w_b \times N_{pred-b} + (1 - w_b) \times N_{obs-b}$
- ▶ $r = \frac{\sum N_{pred-a}}{\sum N_{pred-b}}$
- ▶ $N_{exp-a} = N_{exp-b} \times r$
- ▶ $OR_i = \frac{N_{obs-a,i}}{N_{exp-a,i}}$
- ▶ $OR = \frac{\sum N_{obs-a}}{\sum N_{exp-a}}$
- ▶ $OR_{adj} = \frac{OR}{1 + \frac{Var[\sum N_{exp-a}]}{(\sum N_{exp-a})^2}}$
- ▶ $Var[\sum N_{exp-a}] = \sum [(r)^2 \times N_{exp-b} \times (1 - w_b)]$
- ▶ $Safety\ Effectiveness = 100 \times (1 - OR_{adj})$

RESULTS & DISCUSSION

Empirical Bayes Results

Exit	Road Type	Direction	HSM			ISAT		
			Injury/Fatality	PDO	Total	Injury/Fatality	PDO	Total
			% Safety Effectiveness	% Safety Effectiveness	% Safety Effectiveness	% Safety Effectiveness	% Safety Effectiveness	% Safety Effectiveness
8	Terminal	E	77.96	59.14	64.91	76.61	56.44	62.55
	Terminal	W	32.46	-23.78	-2.94	35.07	-24.63	-2.71
	Ramp	EB/SB Off	100.00	100.00	100.00	100.00	100.00	100.00
	Ramp	EB/SB On	100.00	100.00	100.00	100.00	100.00	100.00
	Ramp	WB/NB Off	-221.38	100.00	-73.39	-275.79	100.00	-87.76
	Ramp	WB/NB On	100.00	100.00	100.00	100.00	100.00	100.00
276	Terminal	E	74.83	74.17	73.95	71.36	70.08	69.57
	Terminal	W	87.27	83.39	85.48	89.12	82.59	85.48
	Ramp	EB/SB Off	60.31	-25.41	0.56	54.36	-23.36	4.65
	Ramp	EB/SB On	100.00	100.00	100.00	100.00	100.00	100.00
	Ramp	WB/NB Off	100.00	57.75	69.94	100.00	53.14	68.59
	Ramp	WB/NB On	76.88	13.29	51.37	81.19	35.65	62.46

Empirical Bayes Results – Continued

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HSM						ISAT		
Exit	Road Type	Direction	Injury/Fatality	PDO	Total	Injury/Fatality	PDO	Total
			% Safety Effectiveness	% Safety Effectiveness	% Safety Effectiveness	% Safety Effectiveness	% Safety Effectiveness	% Safety Effectiveness
278	Terminal	E	82.18	41.90	61.57	78.19	27.65	51.34
	Terminal	W	85.82	89.37	87.85	84.40	88.82	86.88
	Ramp	EB/SB Off	100.00	100.00	100.00	100.00	100.00	100.00
	Ramp	EB/SB On	59.62	53.55	43.61	16.17	16.42	6.93
	Ramp	WB/NB Off	20.85	-22.63	-6.11	-20.40	-87.53	-56.76
	Ramp	WB/NB On	100.00	100.00	100.00	100.00	100.00	100.00
284	Terminal	E	26.51	52.44	45.13	25.21	51.60	44.24
	Terminal	W	43.16	-84.79	-33.10	47.01	-87.52	-32.76
	Ramp	EB/SB Off	12.87	55.78	33.63	-3.15	51.82	29.65
	Ramp	EB/SB On	100.00	58.90	69.52	100.00	50.04	63.26
	Ramp	WB/NB Off	7.55	-196.53	-109.15	29.66	-112.22	-65.64
	Ramp	WB/NB On	-115.34	-32.06	-79.69	-247.70	-67.57	-121.89

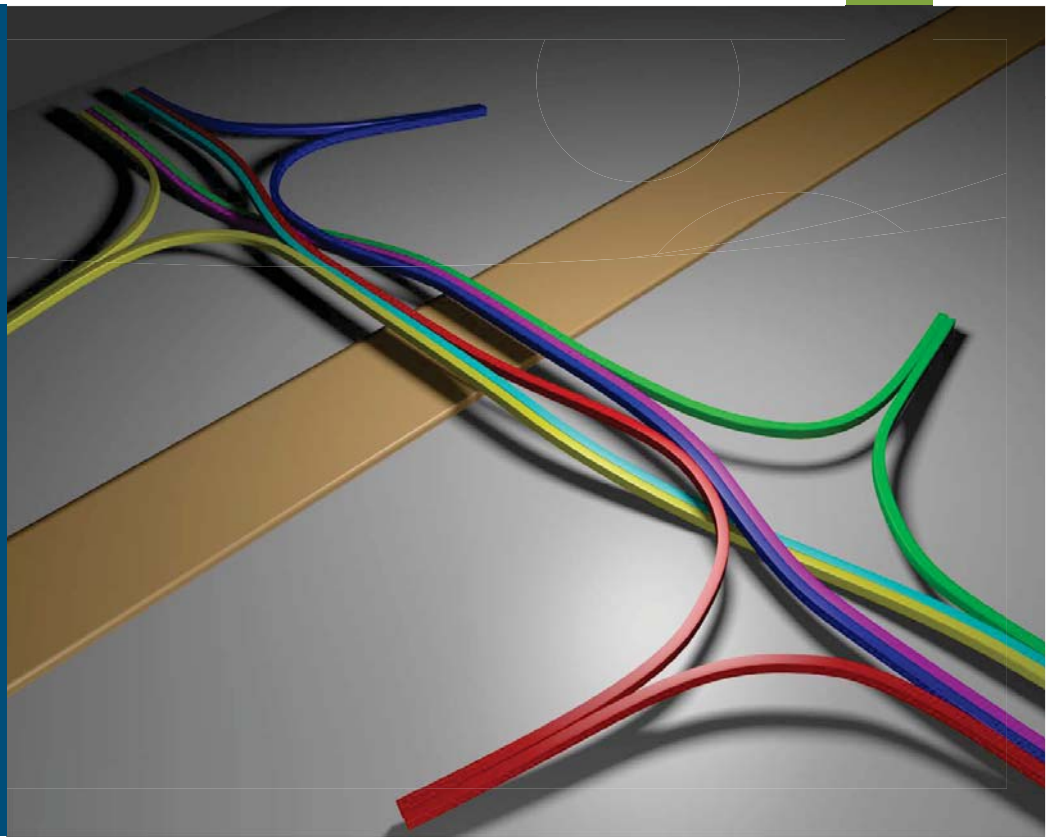
Empirical Bayes Results – Continued

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HSM						ISAT		
Exit	Road Type	Direction	Injury/Fatality	PDO	Total	Injury/Fatality	PDO	Total
			% Safety Effectiveness	% Safety Effectiveness	% Safety Effectiveness	% Safety Effectiveness	% Safety Effectiveness	% Safety Effectiveness
13	Terminal	E	53.88	4.79	26.52	51.03	-1.38	21.90
	Terminal	W	40.68	-14.50	-0.43	43.94	-15.11	0.03
	Ramp	EB/SB Off	-44.89	34.17	3.31	-86.34	11.70	-19.58
	Ramp	EB/SB On	100.00	54.88	62.03	100.00	18.47	27.67
	Ramp	WB/NB Off	64.73	52.59	59.14	65.69	56.96	63.17
	Ramp	WB/NB On	100.00	8.61	13.31	100.00	-32.32	-16.54
Total	Terminal	All	66.63	36.65	50.27	67.94	32.93	47.06
	Ramp	All	50.45	23.87	33.96	41.63	10.39	25.24

Conclusion

- ▶ Overall, the DDIs have had a positive effect on total crashes in terminal areas at the selected locations
- ▶ Large decreases were observed in crashes involving injuries and fatalities at most locations



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Thank you for
participating!

You will be automatically
directed to a short survey,
please take a moment to
provide your feedback.

Transportation Learning Network Contact Information

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Thank you to
our partners:



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