Roundabout Planning

22nd Century

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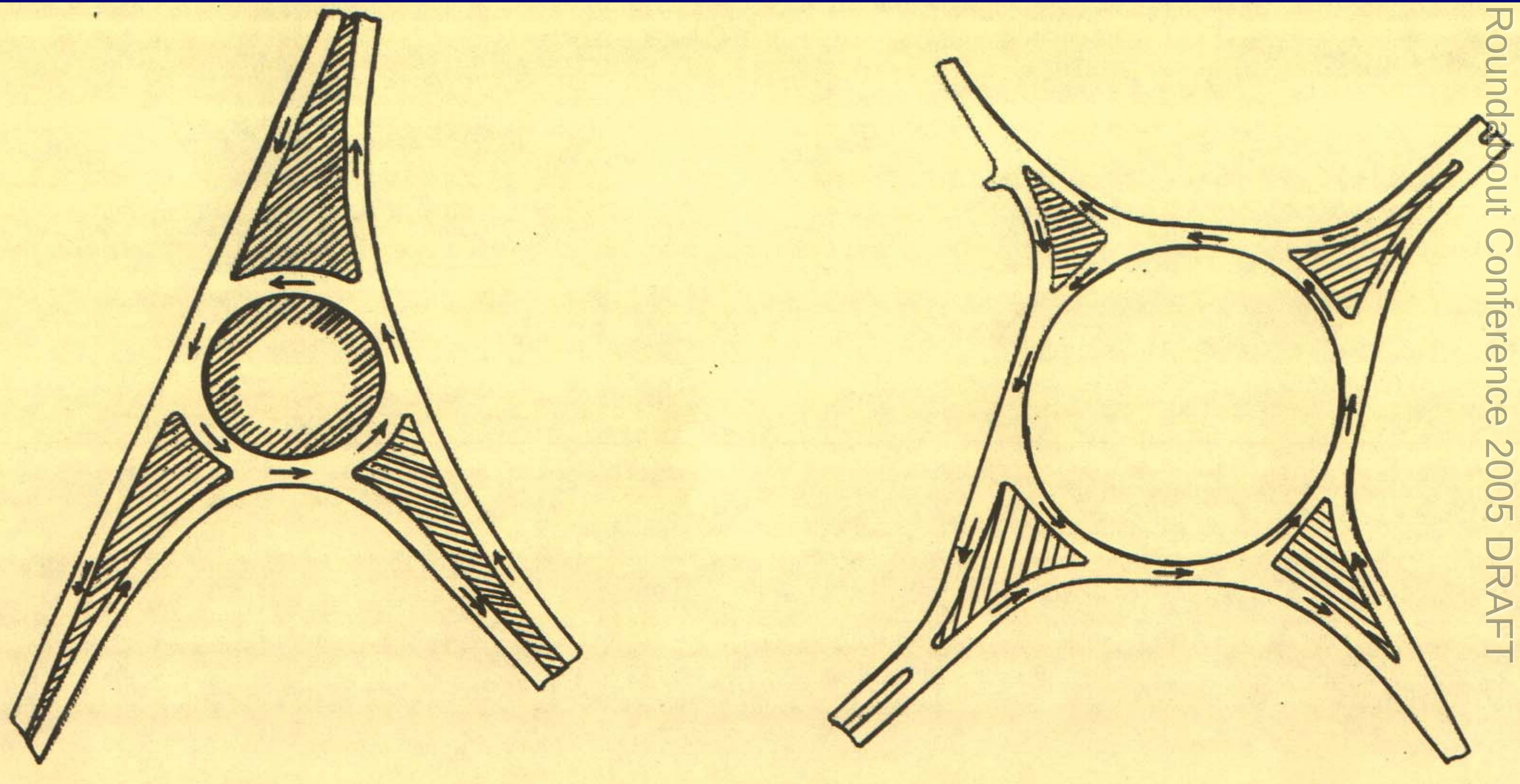
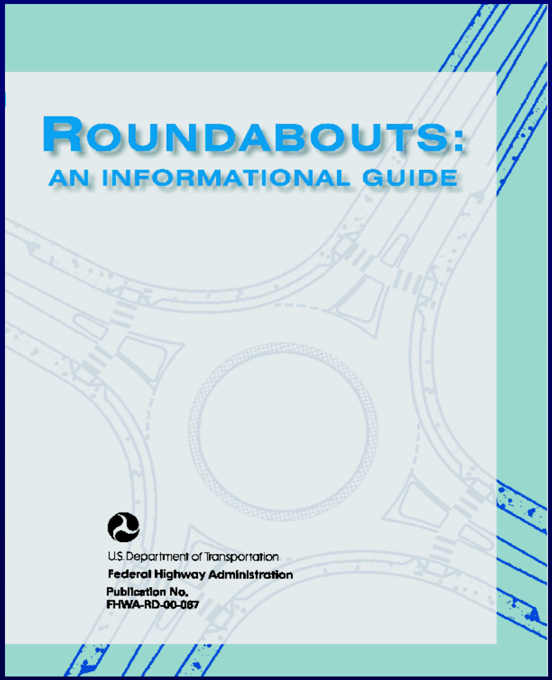
First things first – Open your mind

To achieve something new - Think outside of your experience

Background
Traffic Circles/Rotaries



Today, we're fortunate to have a generalized guide that suggests ….



"The design problem is essentially one of determining a design that will accommodate the traffic demand while minimizing some combination of delay, crashes, and cost to all users, including motor vehicles, pedestrians, and bicyclists.

Generalized Categories of Roundabouts

Urban

Mini	}	Single entry lane
Low Capacity	}	Single entry lane
Moderate Capacity	}	Single entry lane
High Capacity	–	Double entry lanes

Rural

Moderate Capacity	–	Single entry lane
High Capacity	–	Double entry lanes

Generalized Design Features

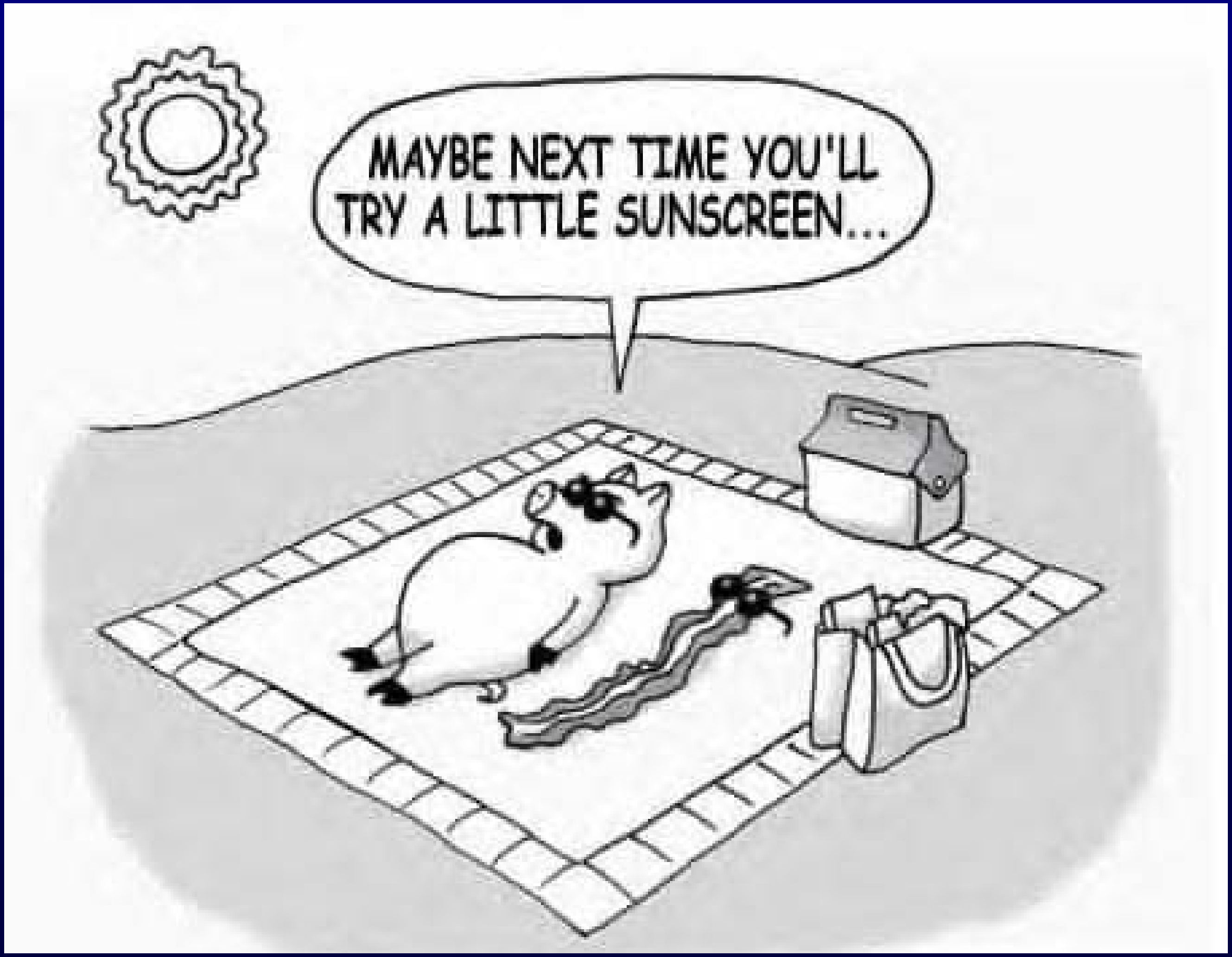
Design Elements	Mini-Roundabout	Urban Compact	Urban Single-Lane	Urban Double-Lane	Rural Single-Lane	Rural Double-lane
Design Speed (mph)	15	15	20	25	25	30
Entering Lanes per approach	1	1	1	2	1	2
Inscribed Circle Diameter (ft)	45 - 80	80 -100	100 -130	150 -180	115 -130	180 - 200
Typical ADT 4-leg Roundabout (veh/day)	10,000	15,000	20,000	Chapter 4 (20-40,000+)	20,000	Chapter 4 (20-30,000+)

And from construction of these, generalized (after-the-fact) safety comparisons

Type of roundabout	Sites	Before Roundabout			Roundabout			Percent change[5]		
		Total	Inj.[3]	PDO[4]	Total	Inj.	PDO	Total	Inj.	PDO
Small/ Moderate[1]	8	4.8	2.0	2.4	2.4	0.5	1.6	-51%	-73%	-32%
Large[2]	3	21.5	5.8	15.7	15.3	4.0	11.3	-29%	-31%	-10%
Total	11	9.3	3.0	6.0	5.9	1.5	4.2	-37%	-51%	-29%

Have all of these been built with an accurate expectation of the result ?

Well we hope so but, action without accurately estimating the result can be VERY expensive.



In Roundabout Planning, many elements need identification and definition before a reasonable decision can be reached.

- **Traffic operations benefits** (but delay of marginal value)
- **Safety benefits** (Nominal Safety versus Substantive Safety)
- **Maintenance savings** (save signal equipment & energy)
- **Environmental enhancement** (less stops, emissions & noise)
- **R.O.W. saving** (more intersection area but less queue storage)
- **Traffic calming / aesthetics / older drivers** (marginal value?)
- **Pedestrian / bicycle operation & safety**

- **Desirable roundabout planning goal ?**

"The roundabout problem is essentially one of determining a design that will accommodate the traffic demand while ***minimizing some combination of delay, crashes, and cost to all users***" **(FHWA Roundabout Guide)** compared to other intersection traffic control types such as TWSC, AWSC or multi-phase signalized.

But HOW do you do that ?

Let's begin with understanding MACRO and MICRO

Macroscopic vs Microscopic

Or
NOMINAL (Macroscopic) versus Substantive (Microscopic)

EXAMPLE

MACROscopic or NOMINAL Planning Model
Highway Capacity Software

(Regression Models about 50-70% accurate compared to field data)

or

MICROscopic or SUBSTANTIVE Planning Model
Netsim / Corsim

- about 75% accurate compared to field data
- vehicle to vehicle interactions

MACROscopic Roundabout Delay Model

(pg. 93 – FHWA Guide)

$$\text{Delay} = \frac{3600}{c_{m,x}} + 900\,T \left[\frac{v_x}{c_{m,x}} - 1 + \sqrt{\left(\frac{v_x}{c_{m,x}} - 1 \right)^2 + \frac{\left(\frac{3600}{c_{m,x}} \right)\left(\frac{v_x}{c_{m,x}} \right)}{450\,T}} \right] + 5$$

Where:

- delay = average control delay (sec/veh)
- V_x = flow rate for movement x (veh/hr)
- c_{mx} = capacity of movement x (veh/hr)
- T = analysis time (hour)

And:

V_x / c_{mx} = from HCM Roundabout analysis (pg. 17-45 & 17-99 (2000 HCM)

HCM ROUNDABOUT DELAY & LOS
Software

2000 HCM ROUNDABOUT CONTROL (Use Lower Bound for High Delay)					EB		NB		WB		SB
LT FLOW RATE	Analysis Period =	0.25		V1	247	V7	143	V4	103	V10	254
THROUGH FLOW RATE		Upper	Lower	V2	308	V8	207	V5	393	V11	94
RT FLOW RATE	Critical gap =	4.1	4.6	V3	105	V9	77	V6	123	V12	152
Effective LANES ON SUBJECT APPR(	Follow-up =	4.1	4.6		1		1		1		1
APPROACH FLOW RATE/lane	(For TS - Assume Follow-up=Critical gap)				660		427		619		500
					V4+V10+V11		V1+V2+V10		V1+V7+V8		V4+V5+V7
CIRCULATING FLOW RATE/lane					451		809		597		639
UPPER BOUND					672		535		613		597
LOWER BOUND					579		447		522		506
CAPACITY/LANE UPPER					672		535		613		597
CAPACITY/LANE LOWER					579		447		522		506
V/C RATIO UPPER					0.98		0.80		1.01		0.84
V/C RATIO LOWER					1.14		0.96		1.19		0.99
APPROACH CONTROL DELAY (2000 HCM Unsignalized +5) =					107.6		62.9		127.7		65.7
APPROACH LOS (2000 HCM) =					F		F		F		F
HCM Compatible Roundabout Delay = 95.08					ROUNDABOUT LOS =		HCM LOS 'F'				

National Roundabout Conference 2005 DRAFT

While some think reduced delay = reduced accidents, often “what seems to be….just isn’t”

So, how do we define this thing called “safety” in general?

Let's look at some situations that may not appear "Safe" ……. Are they?

And the winner …is……. (welding on the gas tank)

So, how do we define <u>traffic</u> safety ….?

Safety Levels of Service
Never Adopted by Engineering Profession
<u>Why Not ?</u>

Prior research says - Government has a Conflict of Interest because the Government entity that designs highways can't also admit to their being unsafe.

THUS:

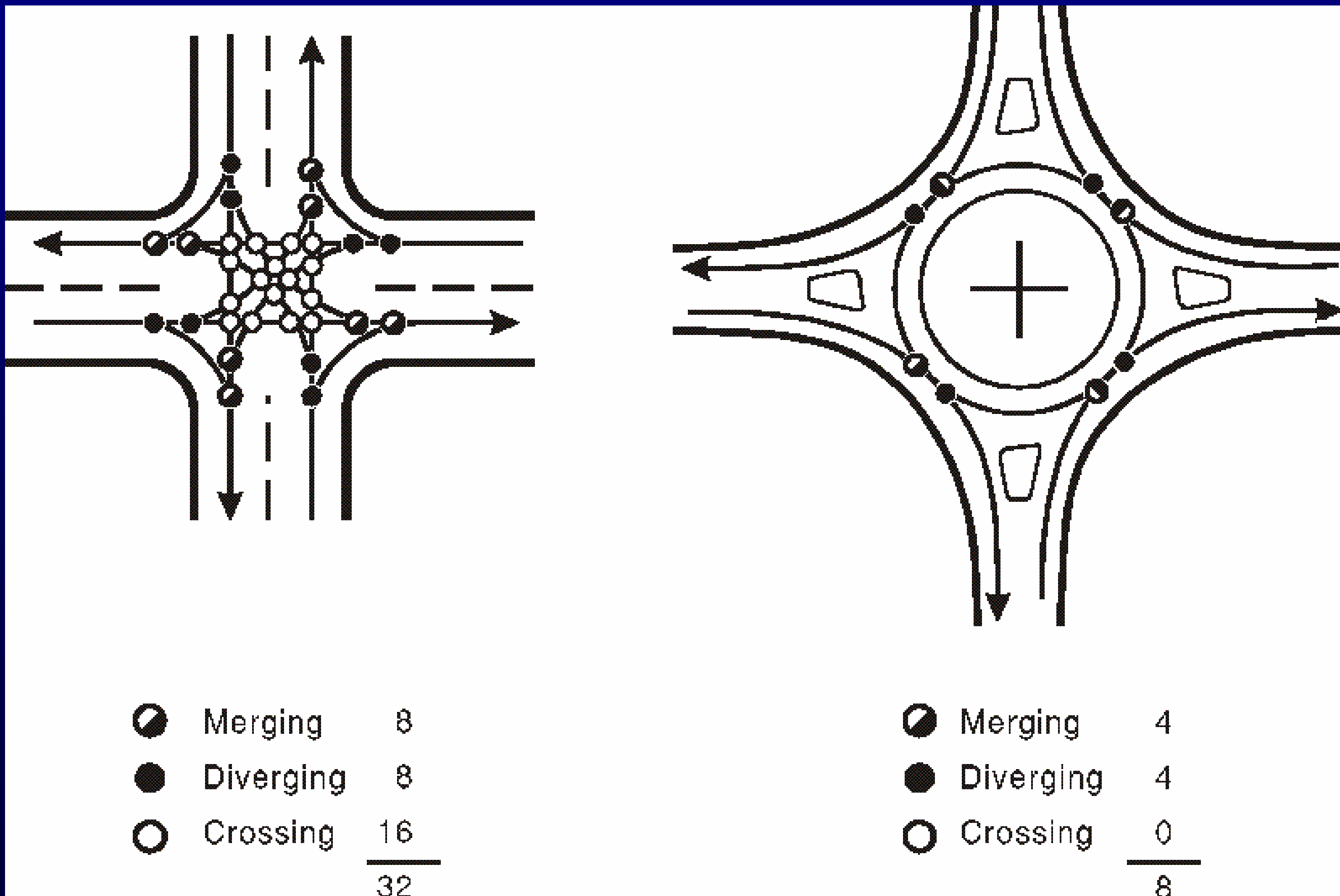
Over Last 25 years - Engineering Profession created the HCM and often assumed Delay as a safety surrogate

OR create "Apparent Safety Models"

(variables are so macro, that the standard deviation is excessive making the models grossly unreliable predictors)

MACROscopic Nominal Safety Model

Comparison of Vehicular Conflict Points



MACROscopic Nominal Safety Model

Injury + Fatal Accidents/yr at Urban 4-leg Signalized

(FHWA-RD-99-094)

	A	B	C	D
1	**Multiple Linear Regression Model**			
2	Injury and Fatal Crashes Urban 4-Leg Signalized Intersections			
3		**ADT Major**	**25,000**	
4		**ADT Minor**	**20,000**	
5		Design Speed	**50**	
6	Variable	Variable Level	Coefficient	Value
7	Intercept		-5.745	1
8	ADT Major		0.574	1
9	ADT Minor		0.215	1
10	Signal Timing	Pretimed	-0.051	0
11		Semi-actuated	0	0
12		Fully actuated	0.4	1
13	Signal Phasing	Two-phase	0	0
14		Multiphase	-0.24	1
15	Access Control on Major	None	-0.29	1
16		Partial	0	0
17	Design Speed on Major (mph)		0.005	50
18	Number of Lanes on Minor	3 or less	-0.155	0
19		4 or more	0	1
20	Number of Lanes on Major	3 or less	-0.163	0
21		4 or 5	-0.151	0
22		6 or more	0	1

ISSUES:

1. INDIVIDUAL VEHICLES ? NO

2. WHAT IF ALL VEHICLES TURN LEFT ? Same RESULT

3. DESIGN SPEED or POSTED SPEED?

4. DATA COLLECTION RADII = 250 ft.
   (Excluded rear-end events in long queues)

Even the BEST FHWA accident models only produced predictions with about 35% accuracy.

MACROscopic Nominal Safety Model

British Roundabout

1	A	B	C	D	E
2	**Injury and Fatal Accidents at Roundabouts**				
3					
4	Flow (Left, Through, Right) (%)	0.10	0.80	0.10	
5					
6					
7	Roundabout Characteristics				
8		Major	Minor	Major	Minor
9	Approach	1	2	3	4
10	e (m) - entry width	11	11	11	11
11	v (m) - approach width	8	8	8	8
12	Di (m) - inscribed circle diameter	60	60	60	60
13	Dc (m) - central island diameter	40	40	40	40
14	Ra (m) - approach radius	300.00	300.00	300.00	300.00
15	Re (m) - entry radius	70.00	70.00	70.00	70.00
16	Pm (%) - proportion motorcycles	0.01	0.01	0.01	0.01
17	Q (degrees) - angle between arms	90.00	90.00	90.00	90.00
18	Pedestrians/day	0	0	0	0
19	ev - approach width correction	88	88	88	88
20	R - (Di / Dc)	1.50	1.50	1.50	1.50
21	Ca - approach curvature	0.00	0.00	0.00	0.00
22	RF - ratio factor	0.73	0.73	0.73	0.73
23	Ce - entry path curvature	0.01	0.01	0.01	0.01

1	G	H	I	J	K	L
2	ADT	45,000				
3						
4	ADT minor/ADT Total	0.44				
5	ADT Major	25,000				
6	ADT Minor	20,000				
7						
8						
9	Approach	1	2	3	4	
10	Q_e (entering flow)	12,500	10,000	12,500	10,000	
11	Q_c (circulating flow)	10,250	12,250	10,250	12,250	
12	Q exiting flow	12,000	10,500	12,000	10,500	
13						
14						
15	Approach	1	2	3	4	
16	*Accident Type*					*Total by Type*
17	Entry - Circulating	0.22	0.20	0.22	0.20	*0.83*
18	Approaching	0.18	0.13	0.18	0.13	*0.62*
19	Single Vehicle	0.29	0.25	0.29	0.25	*1.08*
20	Other	0.13	0.12	0.13	0.12	*0.50*
21	Pedestrian	0.00	0.00	0.00	0.00	*0.00*
22	Total for Approach	0.82	0.69	0.82	0.69	*3.03*
23						
	ROUNDABOUT FATAL & INJURY accidents/year =					**3.03**

BUT, why isn't speed a factor in injury prediction?

Alternative Nominal Macro-models

(Not sensitive to significant variables)

1. Maryland DOT
   a. Annual accidents = 1.53 / mev
   b. Annual injury accidents = 0.11 / mev

2. Other Roundabout Software
   a. Delay based on HCM

   b. Linear regression accident models

$$\text{Crashes/Yr} = \frac{1.64 \times 10^{-12} * \text{ADT 1-way}^{1.17} * \text{Posted Speed}^{4.12} * \text{Length}}{\text{Vehicle Path Radius}^{1.91}}$$

These never mention accuracy of the accident models – accuracy is assumed

…….that's like selecting an open-heart surgeon without checking references…….
Smart?………Good Planning?……..

"Nurse, get on the internet, go to SURGERY.COM, scroll down and click on the 'Are you totally lost?' icon."

Who picked this surgeon?…..I did????

Proper Roundabout Planning – the goal

- Develop preliminary design (Urban-low trucks/low entry speeds or Rural)
- Determine if right-of-way available

- Examine planning steps
  - Think GLOBALLY - Regional considerations
  - Think LOCALLY - Substantive Operations
    - Single / Dual lane ?
    - Speed ?
    - Geometry - Inscribed diameter / central island diameter / bypass lane ?
    - Define SUBSTANTIVE (microscopic) SAFETY elements & value
    - Define NOMINAL (macroscopic) DELAY elements & value
    - Combine SAFETY + DELAY Values ($) to estimate annual performance
    - Compare to Alternate Traffic Control Strategies

- Estimate Potential Safety of Proposed Design (Safety LOS)

Roundabout DELAY Analysis for planning purposes

In planning studies the value of delay is highly variable and is often excluded in the B/C ratio, thus a Macroscopic model like the HCM is generally used to minimize data input needs and the cost of analysis.

Highway Capacity Manual – 2000

with the worst-case assumptions of :

1. Critical gap = 4.6 seconds - similar to Rt. Turn "Yield" of 1985 HCM (5.0 sec), and conforms to 2003 roundabout gap research (4.2 sec at 50% acceptance).
2. No Follow-up time - since each driver must make independent gap selection.
3. Delay is a consistent user-defined $-value over all scenarios

But what about safety?

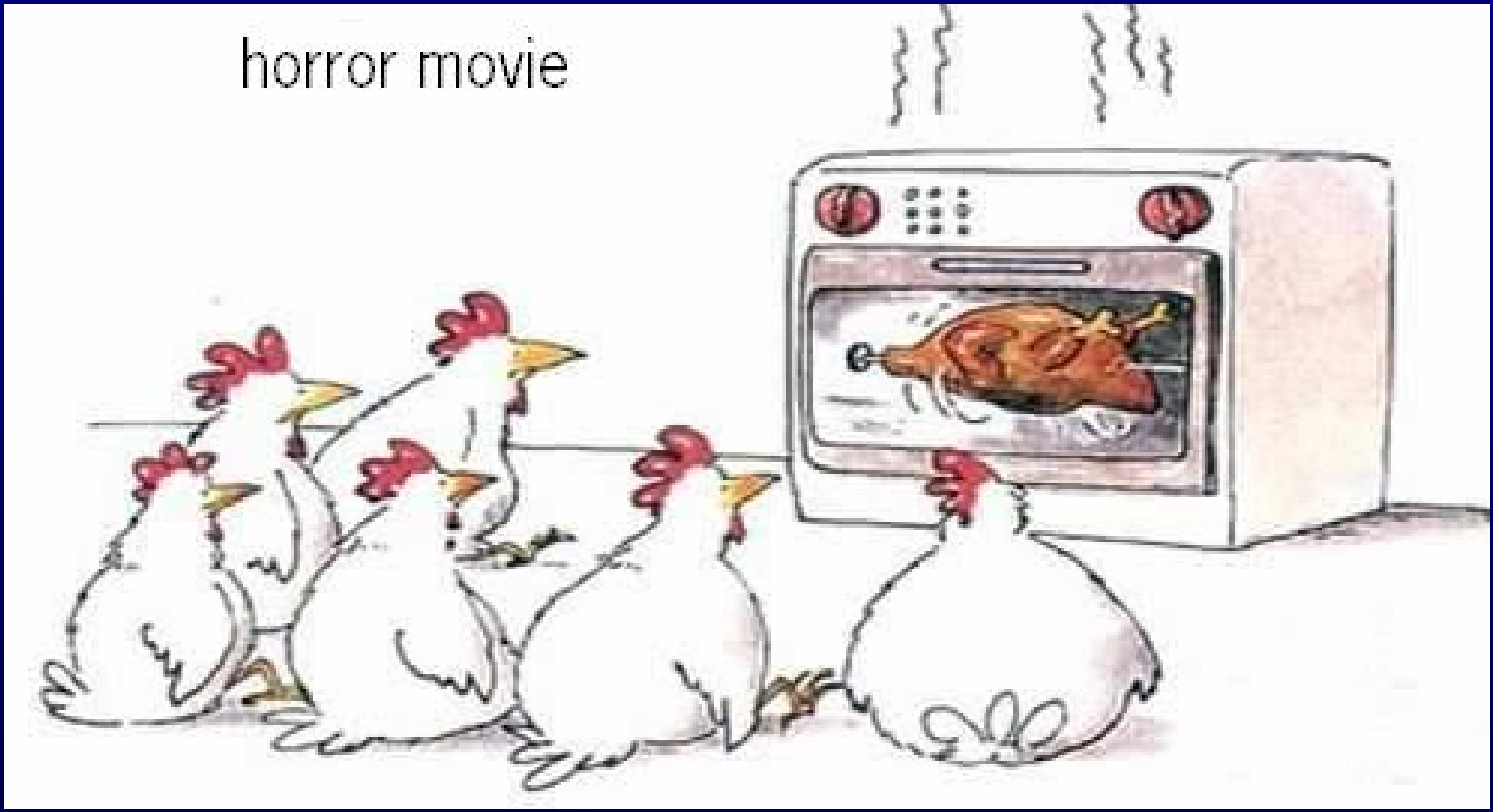
Roundabout SAFETY ANALYSIS

In planning studies the value of safety is entirely dependent on the predicted number and cost of injuries assuming that fatalities are rare & unpredictable events and that fender-bender (pdo) events are an economic benefit that creates jobs and have no negative value, thus the use of a MICROscopic accident prediction model to define injury accidents is ESSENTIAL.

But let's also assume :
If the risk of injury is not unacceptable, thus crashes, injuries (and even unlucky fatal injuries) are expected but undesirable by-products of mobility, and thus some Un-safe events *ARE* undesirable but acceptable.
The problem is: How do you define "some" or how many unsafe events ?

But first – let's talk about MICROscopic accident prediction and then we'll define SAFE versus UNSAFE!

To begin, the one thing you do know about safety is that….if it happened to others…it could well happen to you.



So, rather than waiting for accidents and death to happen & then correct them with "safety programs" which are nothing but lists of failures, we have new technology to help us be pro-active in traffic safety using…..

Traffic Conflicts
as a surrogate for predicting accidents:

1. NOT – Tail light braking conflict studies

2. NOT - Conflict Point comparisons

3. YES - Theoretical "Opportunities for Conflict"

Tail-light braking conflicts

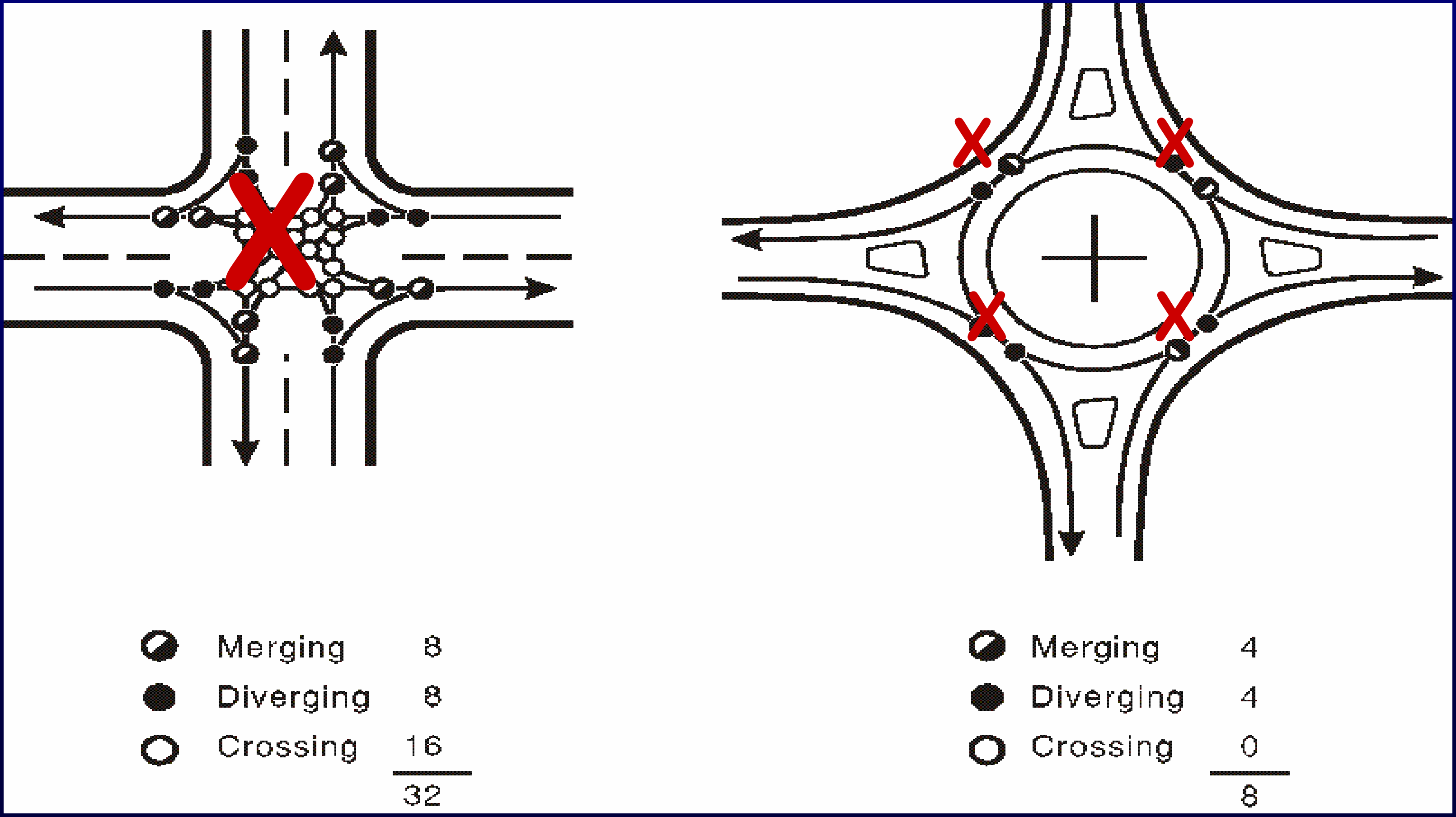
FACT

Actual application of Taillight braking was never found to be consistently correlated to accidents

Conflict Point Comparisons

FACT

Conflict Points are correlated to accident potential but the dynamics are very complex



For Planning Purposes
Define
Roundabout Safety Benefits
with

MICROscopic Sunstantive Model
based on individual vehicle
conflict-opportunities

(Traffic Safety Software @www.TRAF-Safe.com)

<u>Assumptions for conservative analysis:</u>

1. Fatal events are not estimated or valued but are added to injury accidents.
2. Injury and vehicle damage are consistent user-defined $values.

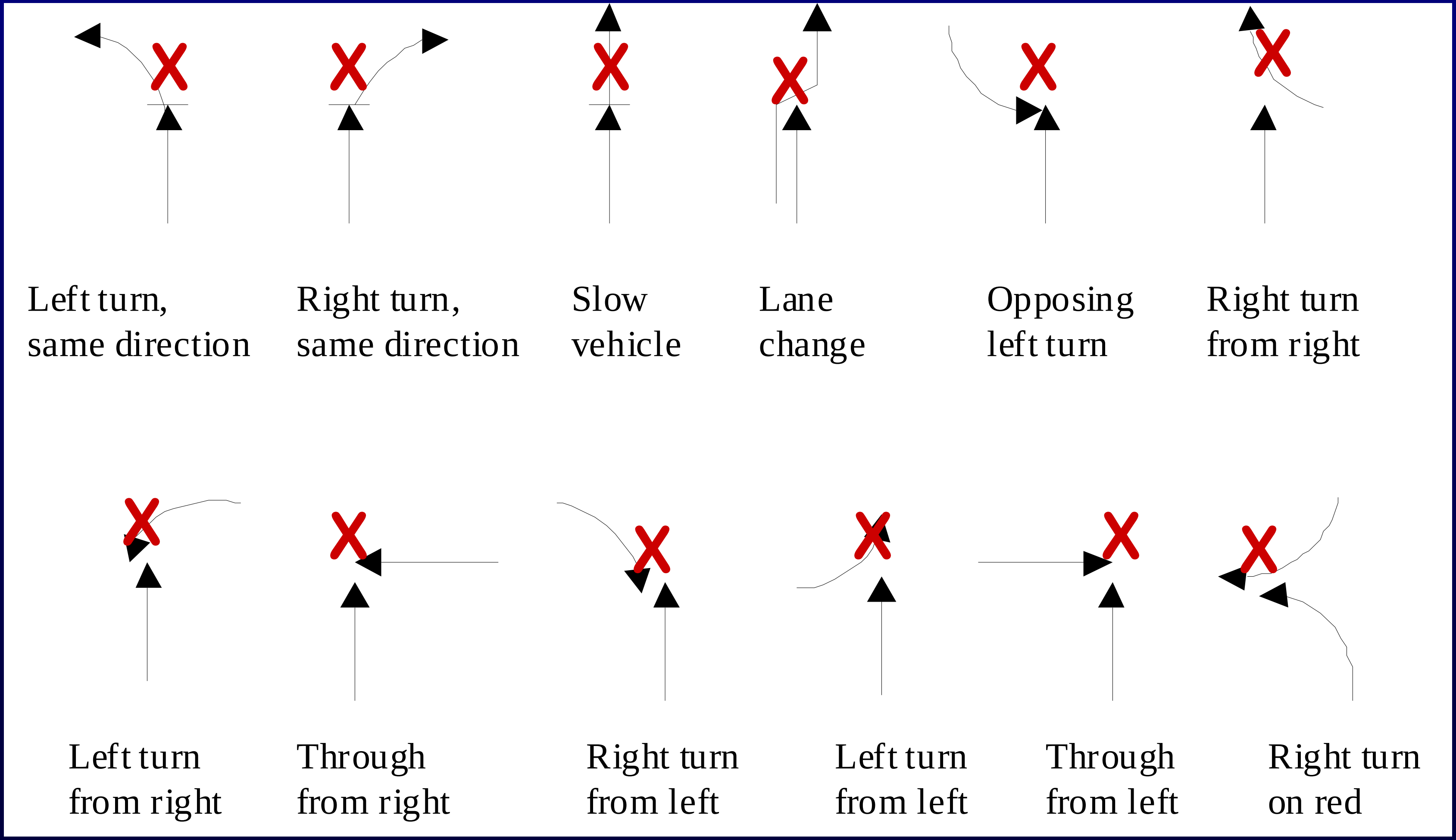
What is a
Conflict Opportunity?

An actual occurrence in which 2 or more vehicles or users approach one another such that there is a theoretical probability of collision assuming unchanged trajectories.

Theoretical Opportunities for Conflict

FACT

Highly correlated to annual accidents – as you might expect !



University of Virginia/VDOT
VTRC Report 04-R11

"Development of Left Turn Lane Guidelines"
March 2004

Recommendations

"The safety surrogate measure used in this study was solely based on conflict opportunities."

"Future research should quantify the extent to which conflict opportunities can predict crashes such that the impact of safety can be better incorporated …" (pg. 46)

Conflict Opportunity Accident Research

1. **"Predicting Annual Intersection Accidents with Conflict Opportunities"** presented to TRB, Washington, D.C., January, 2001 and published in the proceedings of the AASHTO/ITE/TRB Urban Street Symposium; A.R. Kaub & K.M. Taylor, Dallas, Texas; June,1999 www . nationalacademies.org/trb/publications/ec019/ec019.pdf

2. **"A Corridor Road Safety Audit with Safety Software"** presented to TRB, Washington, D.C., January 2000 and published in the proceedings of the ITE Conference New Tools for Enhancing Transportation Safety in the 21st Century, A.R. Kaub & J.A. Kaub, Orlando, Fl., 1999.

3. **"Predicting Annual Intersection Accidents with Conflict Opportunities"**, presentations to University of Virginia Civil Engineering / VTRC / VDOT planning staffs, A.R. Kaub, 1995-1999.

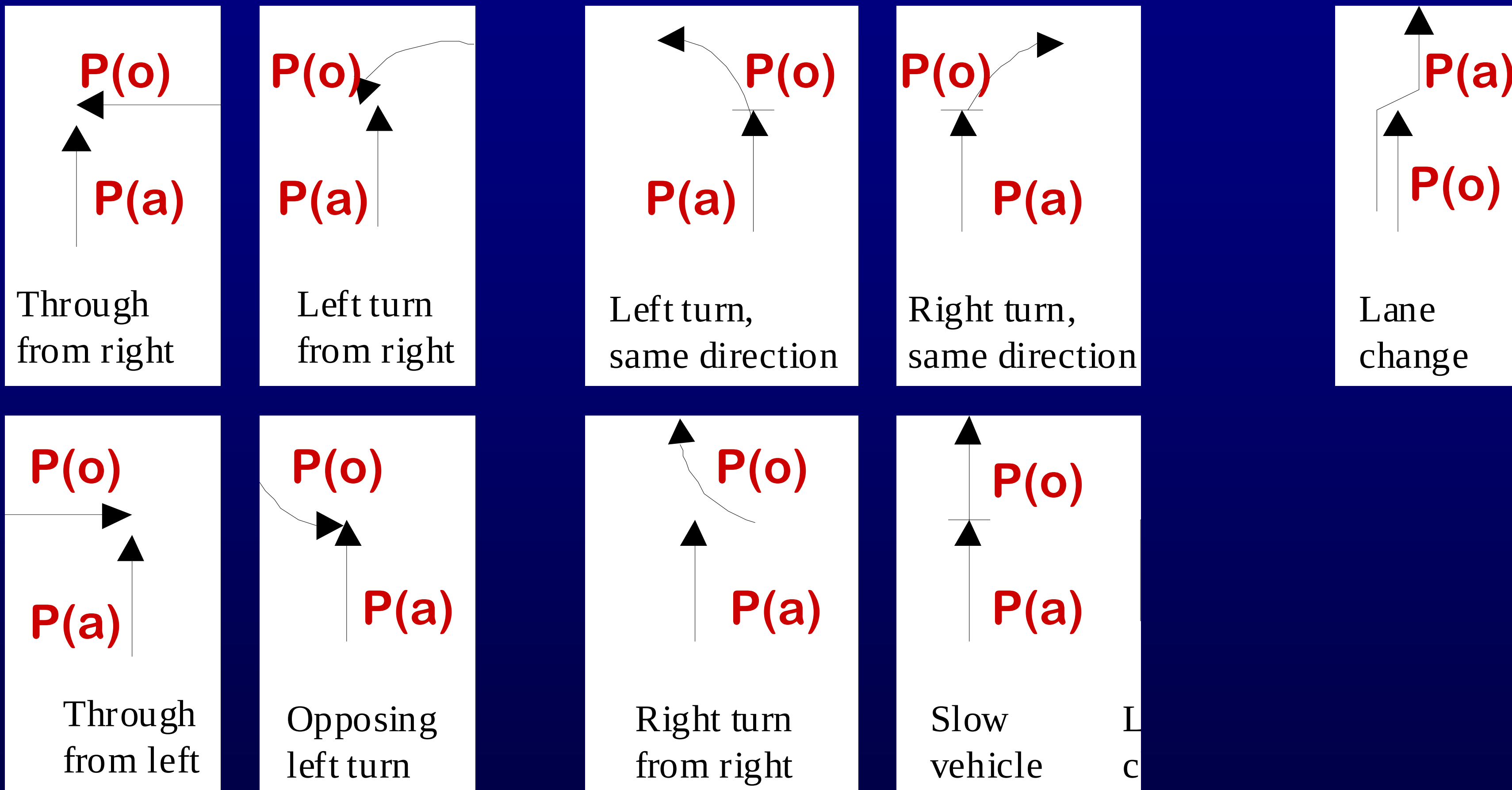
4. **"Validation of a Conflict Opportunity Intersection Accident Prediction Model"** presented to TRB, Washington, D.C., 1998 and published in the proceedings of the TRB 2nd Access Management Conference; A. R. Kaub, Vail, Colorado; 1996.

5. **"Validation of the Probable Conflict Opportunity Accident Software for Two-way Stop Control Intersections",** Florida DOT Research Contract # B9212, A.R. Kaub, 1996.

6. **"Managing Highway Access with Conflict Opportunity Crash Prediction Software"** A.R. Kaub, presented to the USDOT, FHWA/Turner-Fairbank Safety Research, 1993.

7. **" Design Guide for Auxiliary Passing Lanes on Rural Two-Lane Highways using Conflict Opportunity Accident Estimation"**, A.R. Kaub & W.D. Berg, TRR 1195, 1987.

Angle Conflicts + **Rear-End Conflicts** + **Sideswipe Conflicts**



+

Fixed Object / Single Vehicle Events

What is Conflict Opportunity Technology?

Originally Based on 1968
General Motors Conflict Opportunity Research

by Perkins & Harris

Angle Accidents = ƒ(Angle Conflict Opportunities)
Rear-End Accidents = ƒ(Rear-end Conflict Opportunities)
Sideswipe Accidents = ƒ(Sideswipe Conflict Opportunities)
Fixed Object/Single Vehicle Accidents = ƒ(FO/SV Conflict Opportunities)

But
GM couldn't integrate these into Total Annual Accidents

Today's Conflict Opportunity Technology does what GM couldn't do

Assumptions

- Typical Drivers, Vehicles, Environment, Profile, Adequate SD
- 4 Conflict Types- Angle, Rear-end, Sideswipe, Single Vehicle

Common Poisson Conflict Opportunity Forms

$$P(\text{Arrival}) = e^{-\text{mean arrival flow rate}} \quad \& \quad P(\text{Opposition}) = e^{-\text{mean opposing flow rate}}$$

(Arrival Exposure Time)

$$\text{Probability of Conflict}_{(\text{angle, rear,side,single})} = P(\text{ Arrival}) \times P(\text{Opposition })$$

Annual Summation of Independent Conflict Types

Annual Conflict Opportunities = ± a (P-Angle CO) ± b (P-Rear end CO) ± c (P-Sideswipe CO) ± d (P-Single Vehicle)

a,b,c,d = Speed-based coefficients calibrated to National Accident Data using the drivers visual perceptive capability for each type of conflict

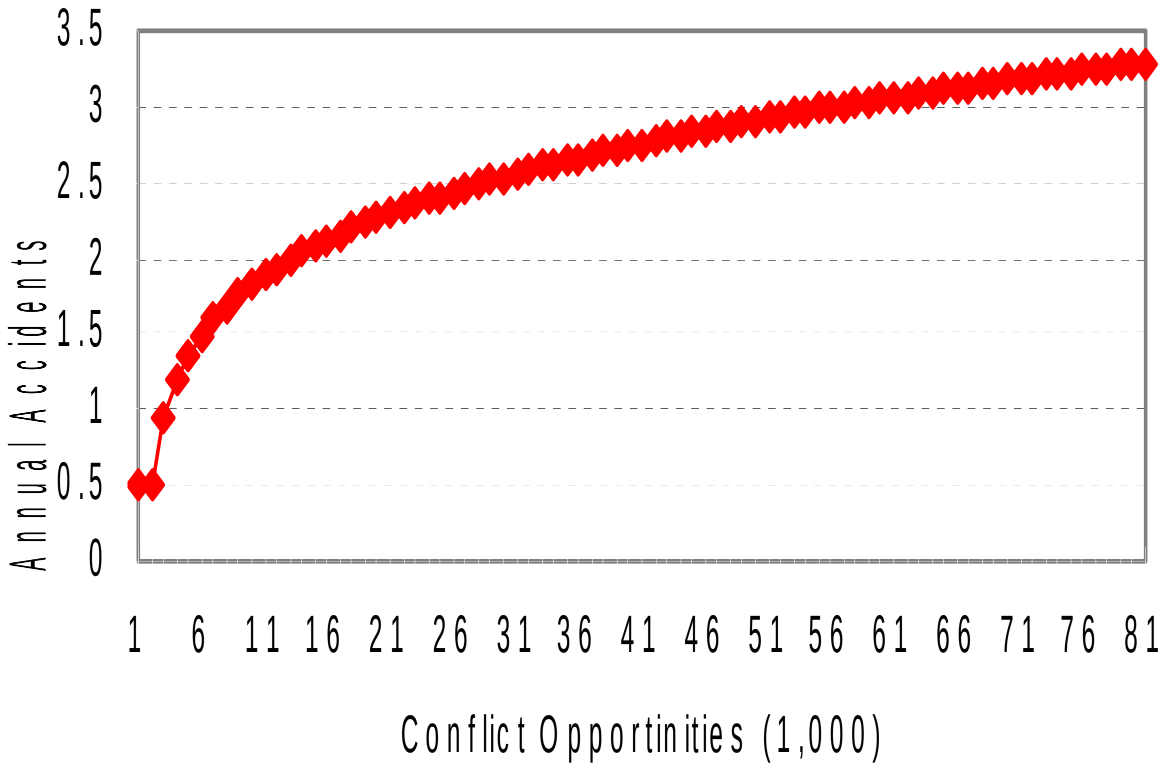
Convert Annual Probable Conflict Opportunities to Annual Accidents

$$\text{Annual Accidents} = \frac{\text{Total Annual Conflict Opportunities}}{\text{Conflict Opportunity/Accident Ratio}}$$

$\frac{\text{Conflict Opportunity}}{\text{Accident Ratio}}$ = Family of Curves calibrated to speed, geometry, volume for each type of traffic control device

Example Annual Conflict Opportunity/Accident Ratio

(One of a Family of Volume, Geometry, and Speed, Dependent Curves)



At low volumes, it takes few opportunities for conflict to generate one accident, but at higher volumes it takes exponentially increasing opportunities to generate that same accident.

That's because as volume increases, both reduced speeds and car-following aid the drivers visual perception to generate safer operation over all accident types.

Finite Element Analysis

Finite Element Analysis
Finite Element Analysis

Finite Element Analysis

Finite Element Analysis

Finite Element Analysis

Time Finite Element Analysis

Lane Finite Element Analysis

Approach Finite Element Analysis

Traffic Control Finite Element Analysis

Intersection Finite Element Analysis

Corridor Finite Element Analysis

New Accident & Injury Prediction Technology

Inputs

Traffic Control selection (TWSC, AWSC, Signal or Roundabout)
Peak Hour Am and Pm volume by lane with other hours interpolated
Approach geometry & turn bay length
Approach speeds & turning radii
Numerous HCM-based vehicle & flow variables
Actuated Signals (each hour of day)
Automatic - Cycle length and phase selection
Automatic - Through and turn phase duration
Automatic - Hourly timing plans using sophisticated ICU

Almost 150 HCM Compatible INPUTS

Outputs

Hourly and Annual Delay

Hourly & Annual Accidents

Injury-based Safety Levels of Service & Lifetime Risk of Injury

&

Performance Index

$\sum$ **Utility ($Delay/yr + $Injury accidents/yr)**

<u>Planning and Design Goal:</u>

If the traffic control type selection is “Safe”, then minimize Performance Index (minimum delay and injury values) and over all “Safe” types of traffic control devices.

So Unique - US Patent # 6,662,191

United States Patent **6,662,141**

December 9, 2003

Traffic safety prediction model

Abstract

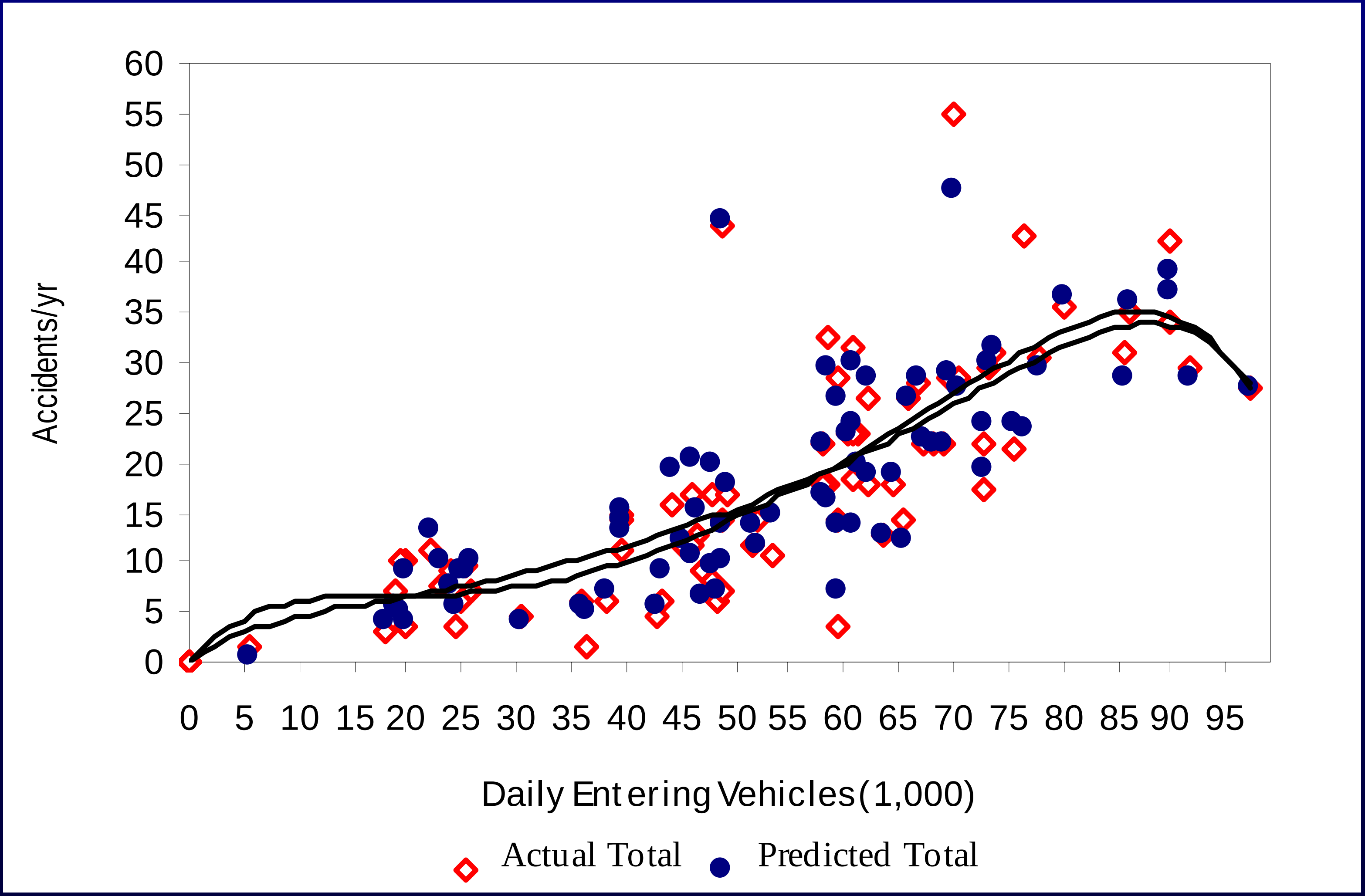
A Traffic Safety prediction Computer Program (TRAF-SAFE) and sub-models for predicting the number of accidents, injuries and fatalities expected annually at an intersection or series of intersections based on the particular intersection and roadway features. A finite analysis approach to an intersection is used to break the intersection into discrete elements such as lanes, turnbays, stop control signals, and traffic flow rates. The total annual expected accidents can then be calculated as a summation of the interrelation of the individual elements. A Poisson's distribution is used to statistically estimate the likelihood of the individual vehicles occurring within a discrete time frame being investigated. The conflict probabilities between various permutations of the traffic flow is then calculated and summed to determine the number of conflicts for the intersection or roadway. The conflicts are then converted to expected accidents, and the accident level is converted to injury involvements and Safety Levels of Service for the intersection and roadway.

Ya, sure I read all about it…

…but how do I know it works?

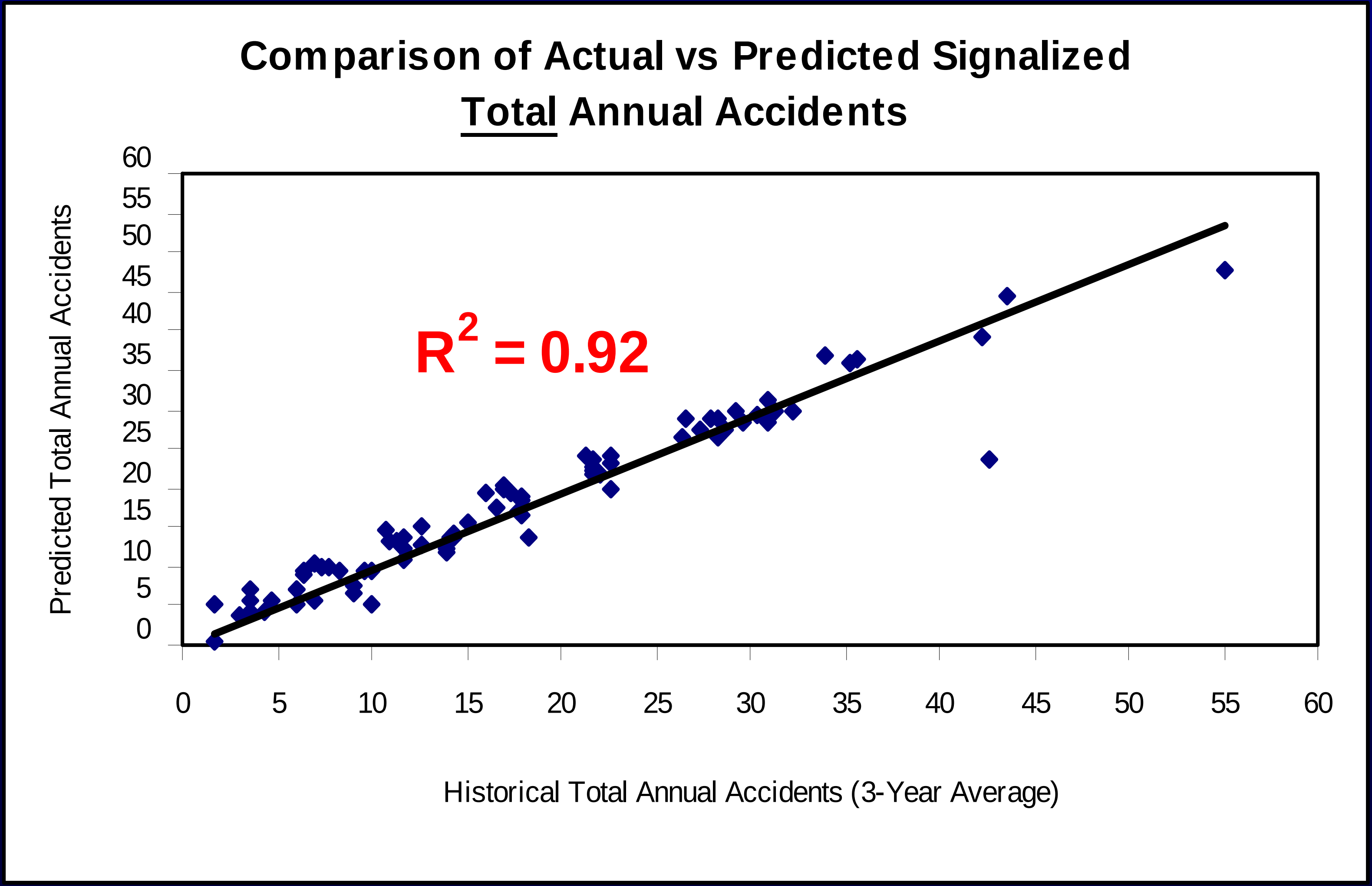
Signals Total Accidents/yr

(Northern Virginia Actual Site Data and Accident History)



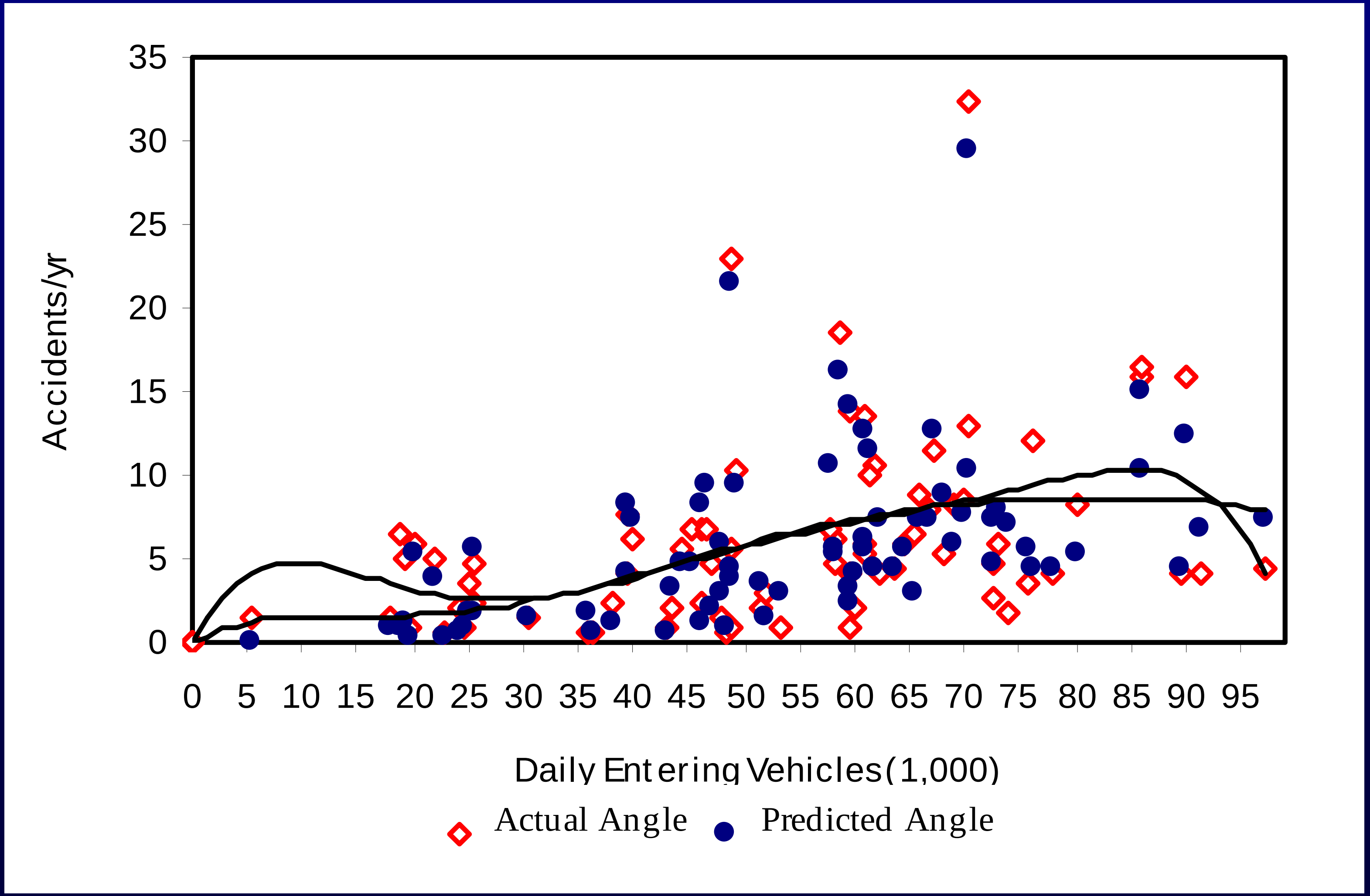
Signals Total Accident Validation

(Data From 100 Signalized Intersections in Northern Virginia)



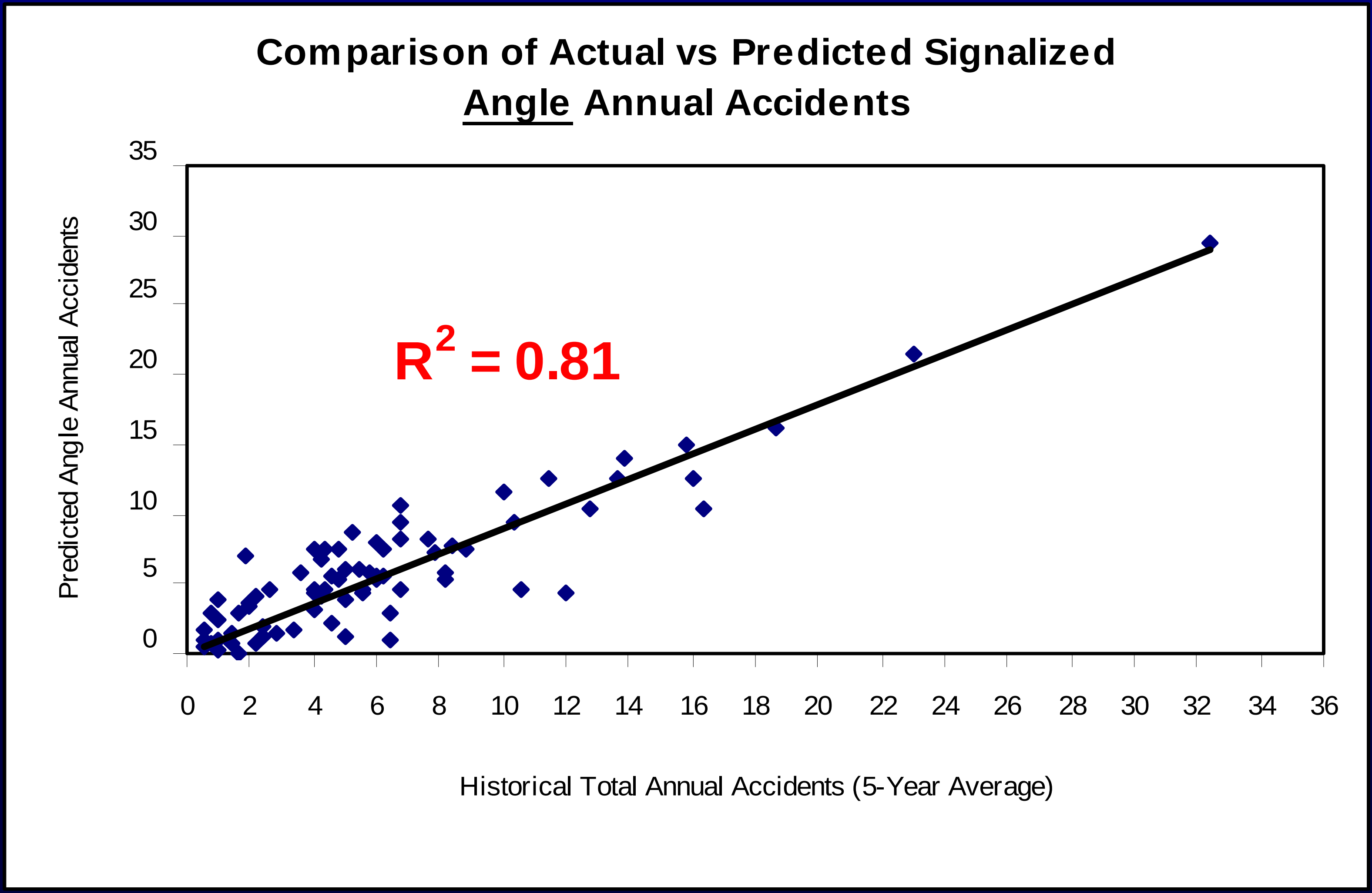
Signals Angle Accidents/yr

(Northern Virginia Actual Site Data and Accident History)



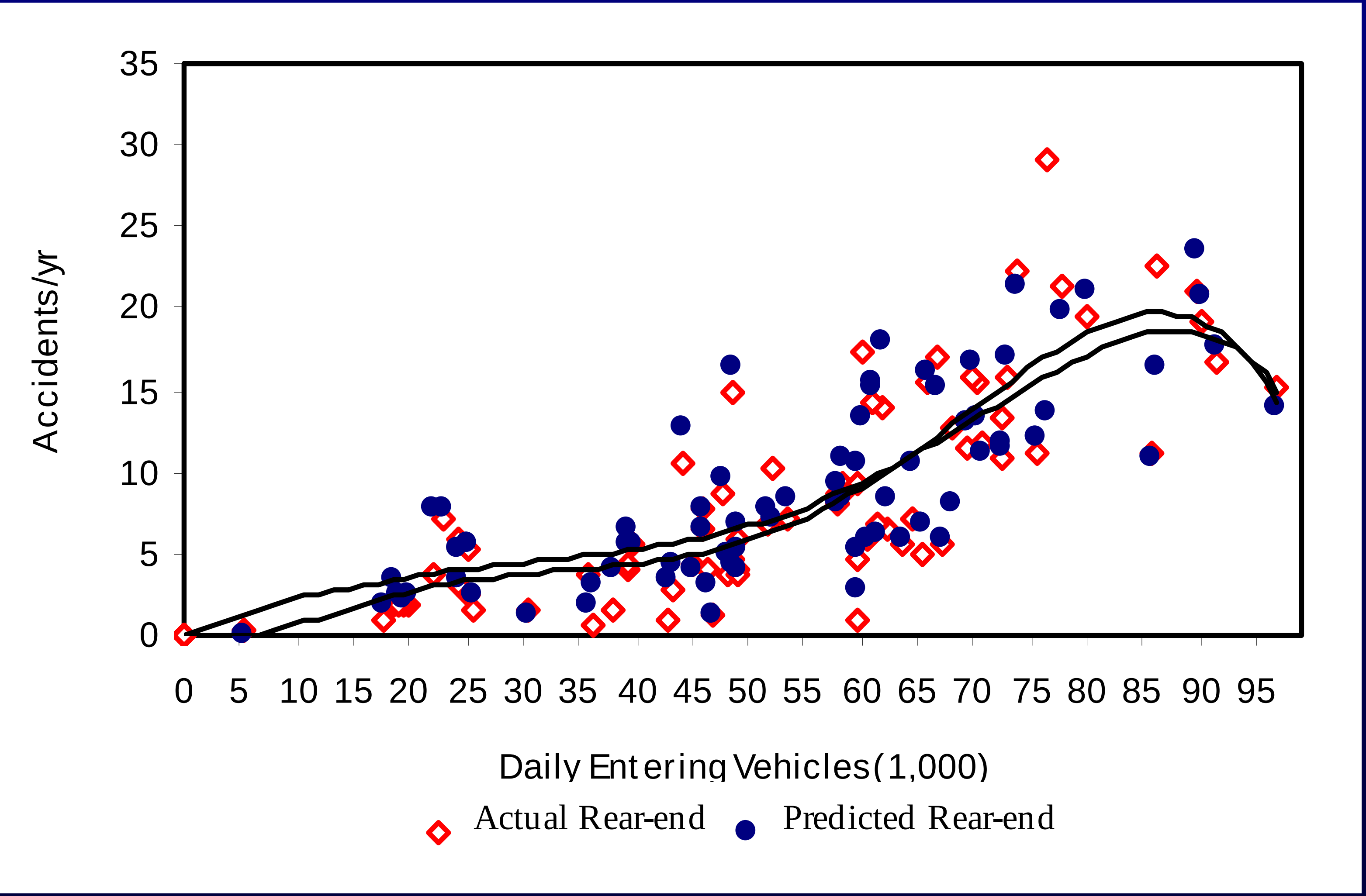
Signals Angle Accident Validation

(Northern Virginia Actual Site Data and Accident History)



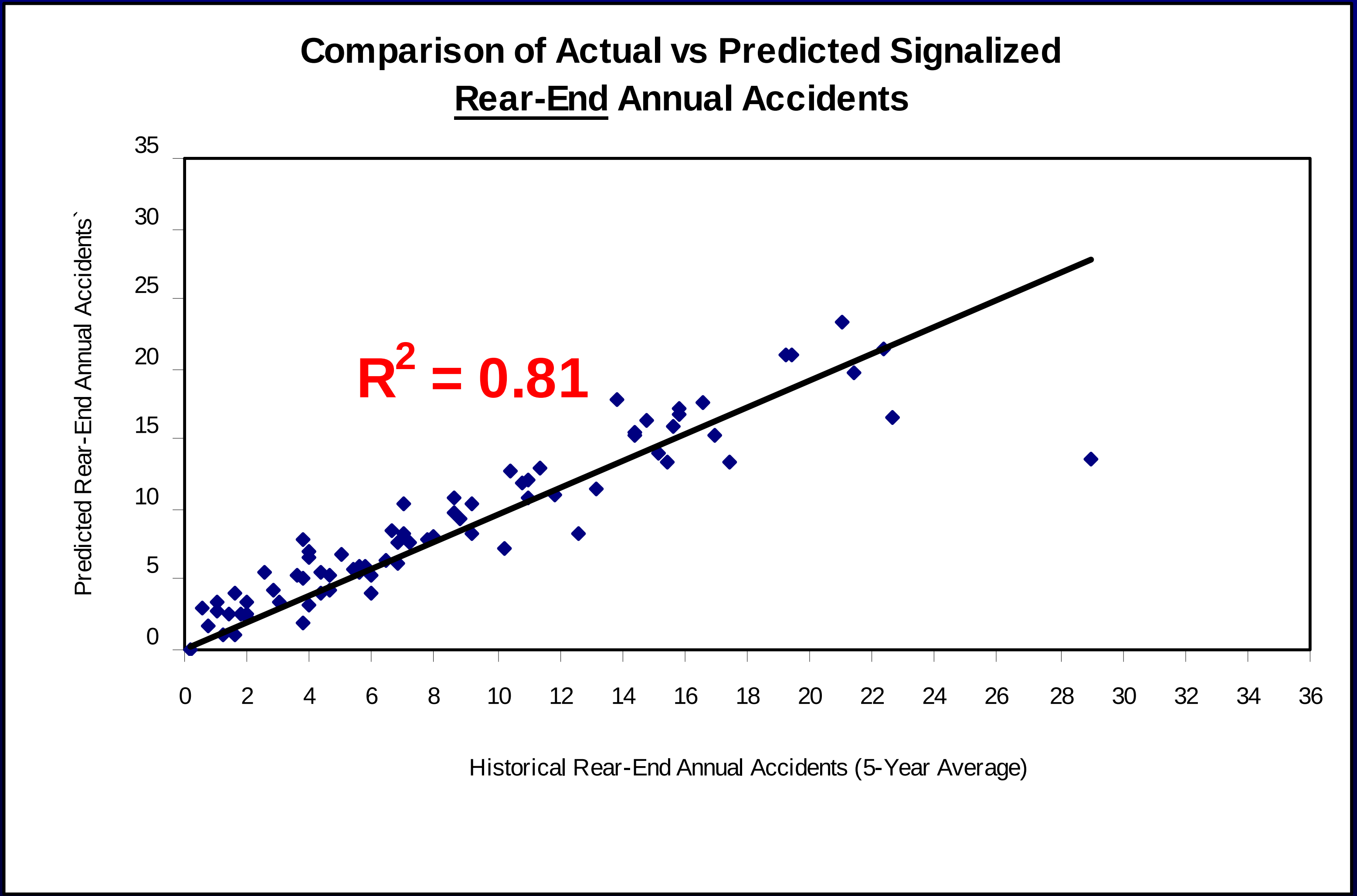
Signals Rear-End Accidents/yr

(Northern Virginia Actual Site Data and Accident History)



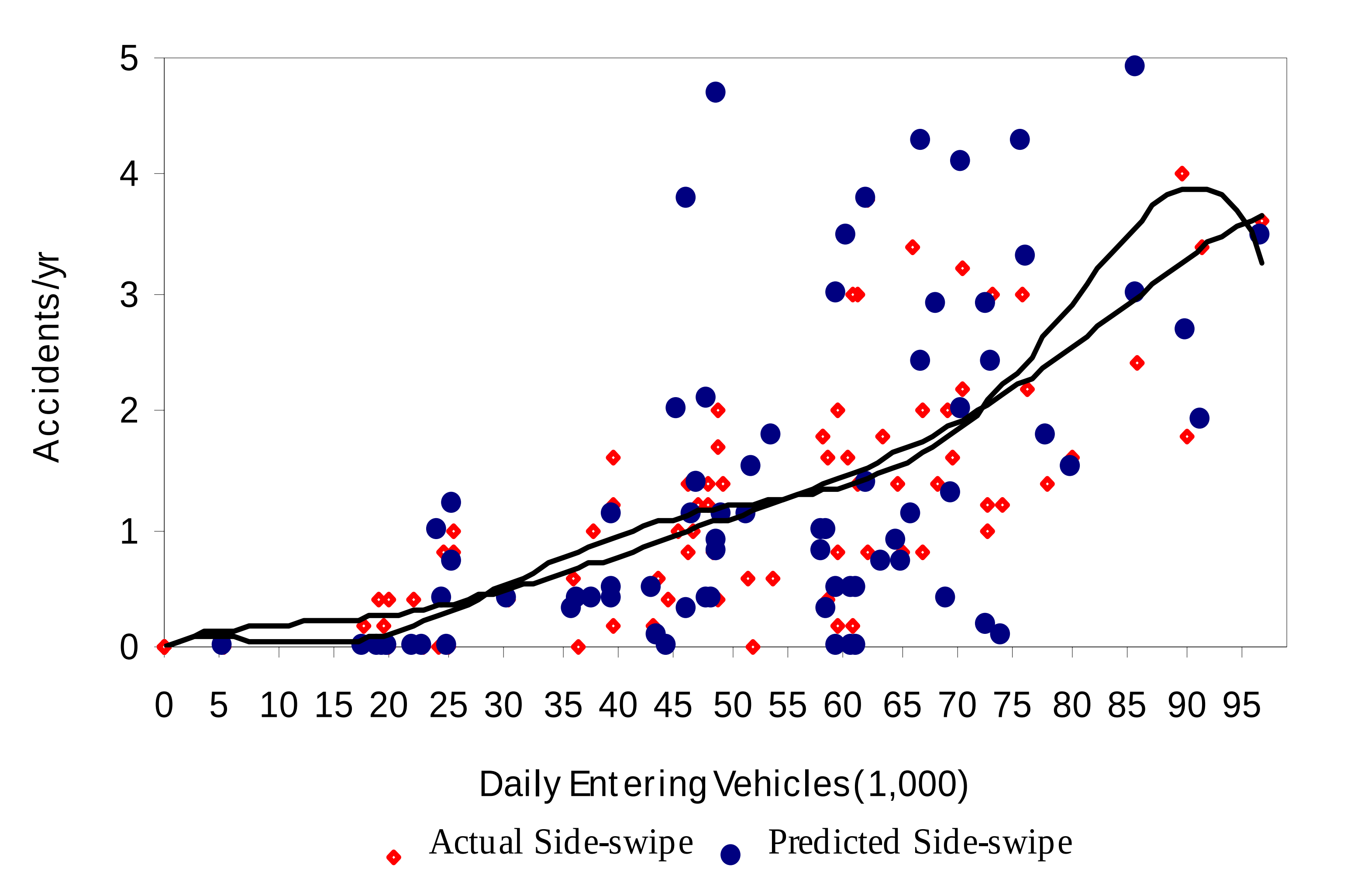
Signals Rear-End Accident Validation

(Northern Virginia Actual Site Data and Accident History)



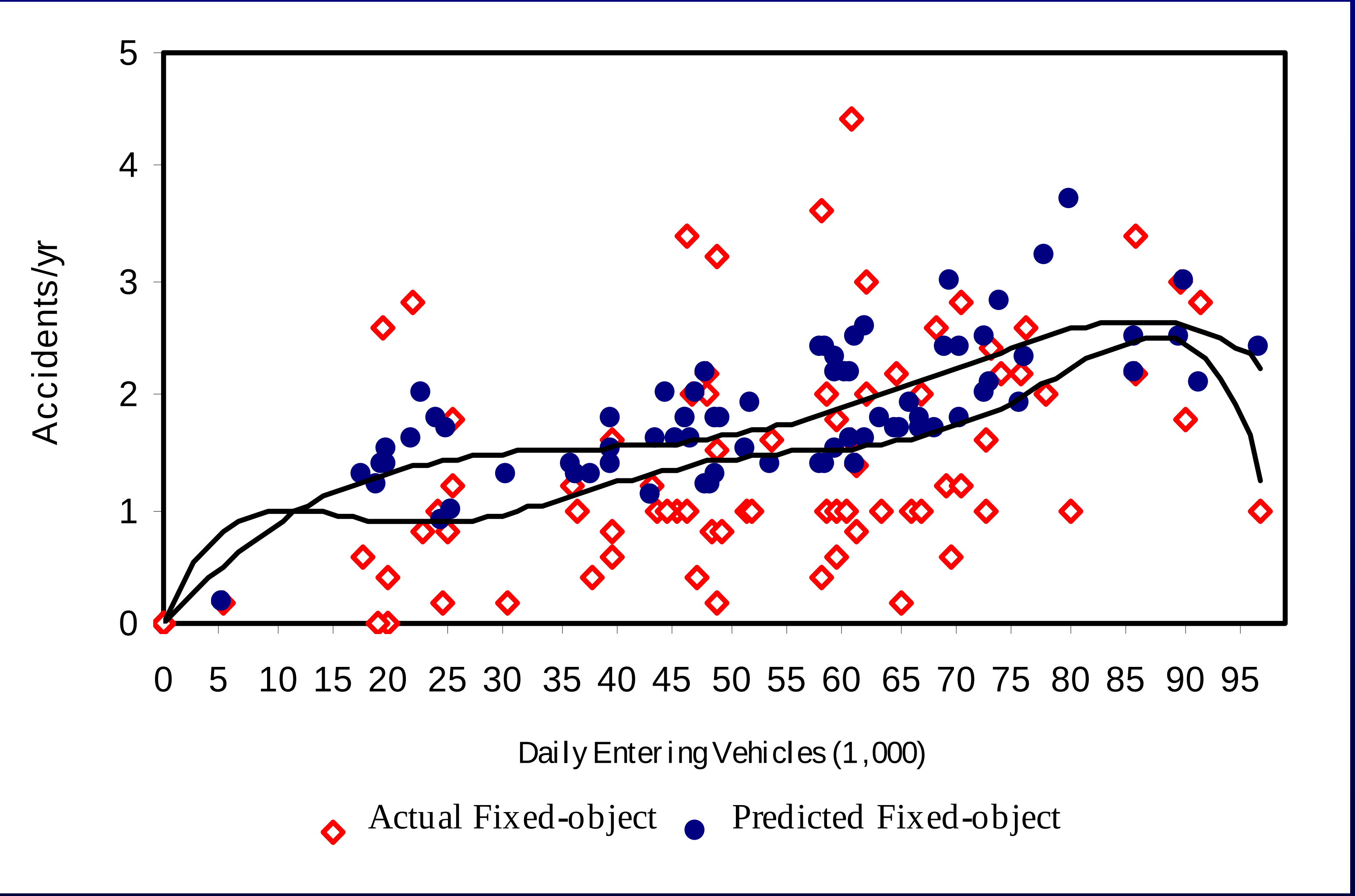
Signals Sideswipe Accidents/yr

(Northern Virginia Actual Site Data and Accident History)



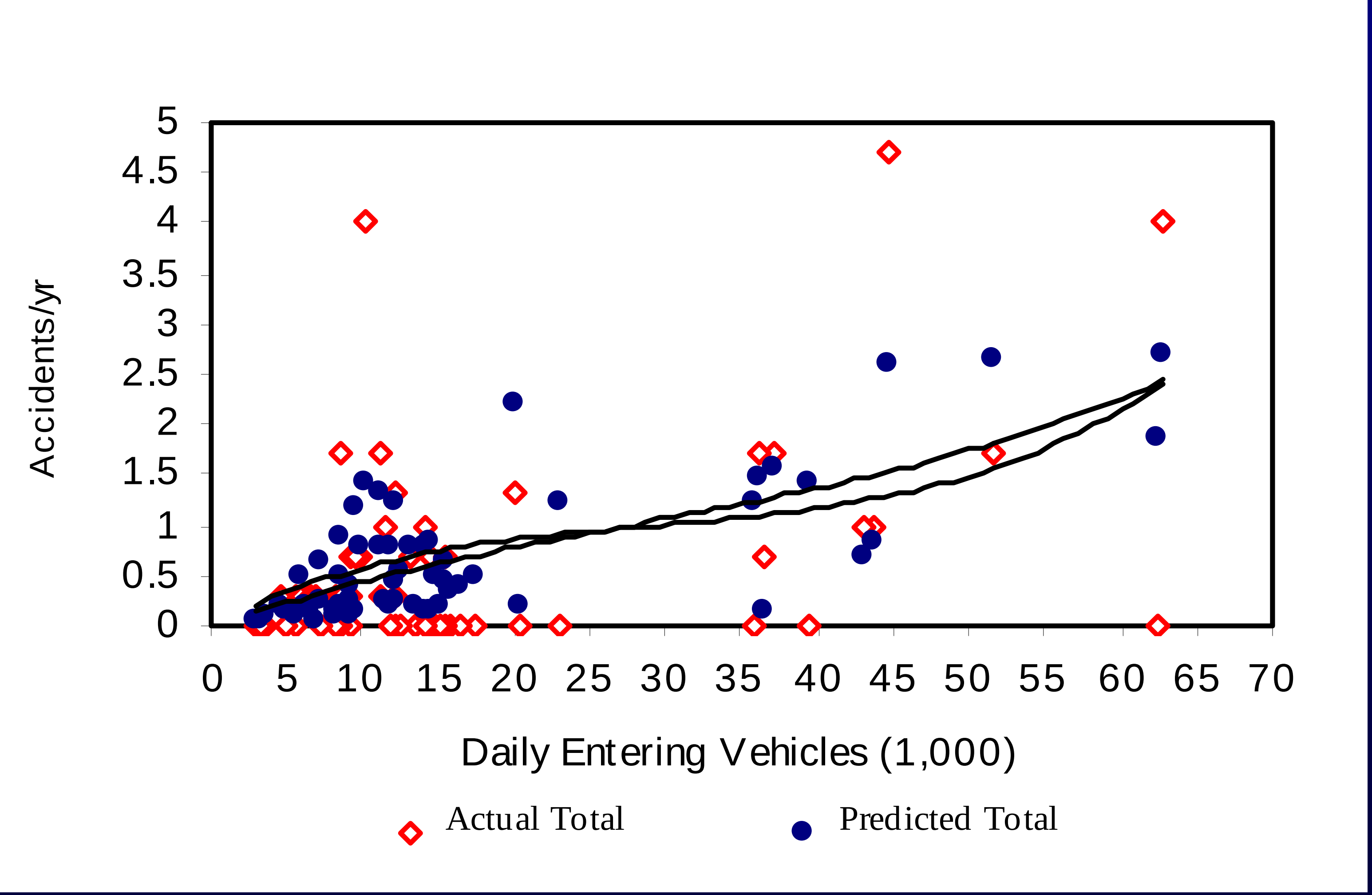
Signals Fixed Object/Single Vehicle Accidents/yr

(Northern Virginia Actual Site Data and Accident History)

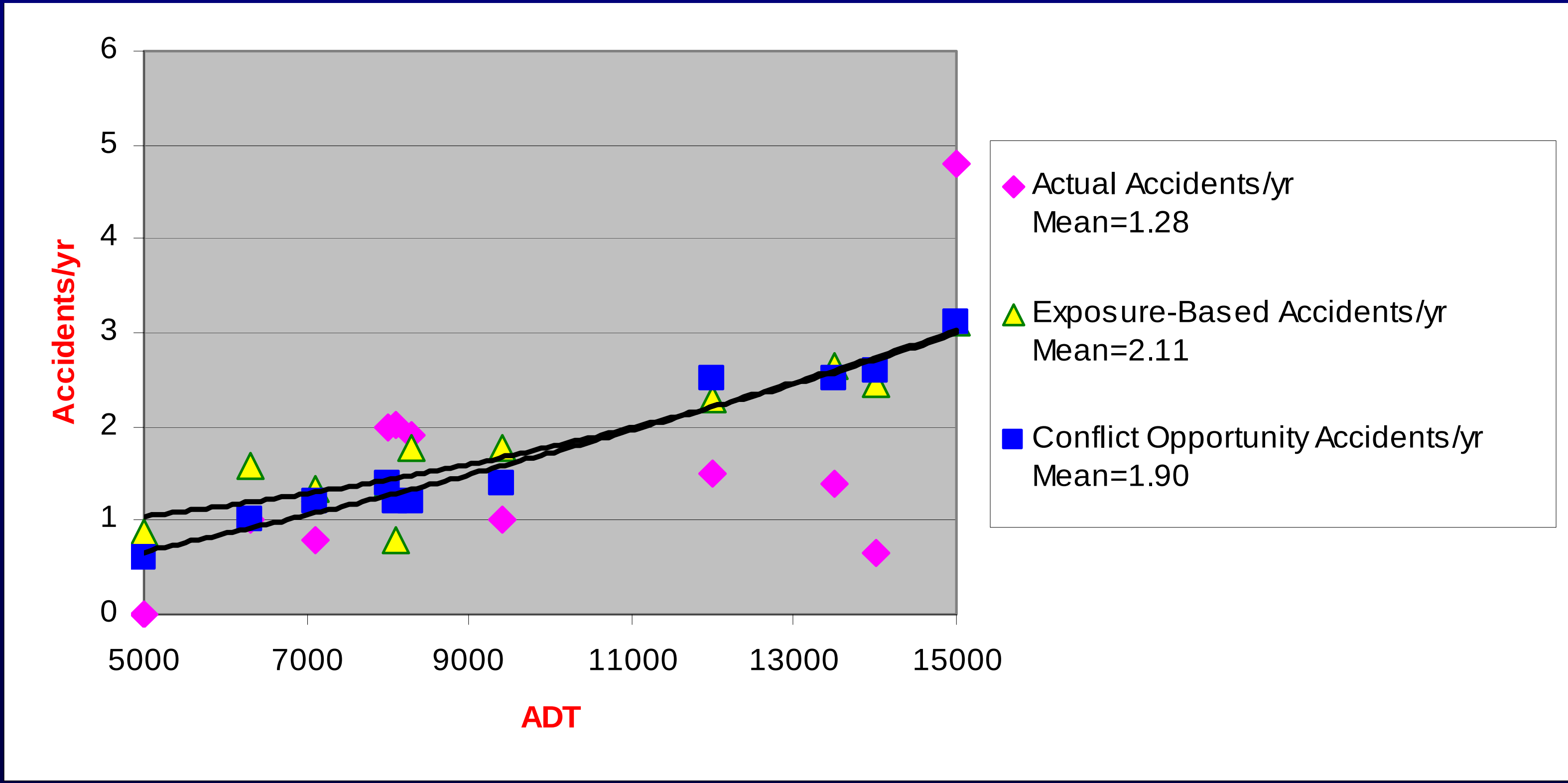


Unsignalized TWSC Total Accident Validation

(2-Way Stop Data From 65 Unsignalized Intersections, Tampa Bay, Florida)



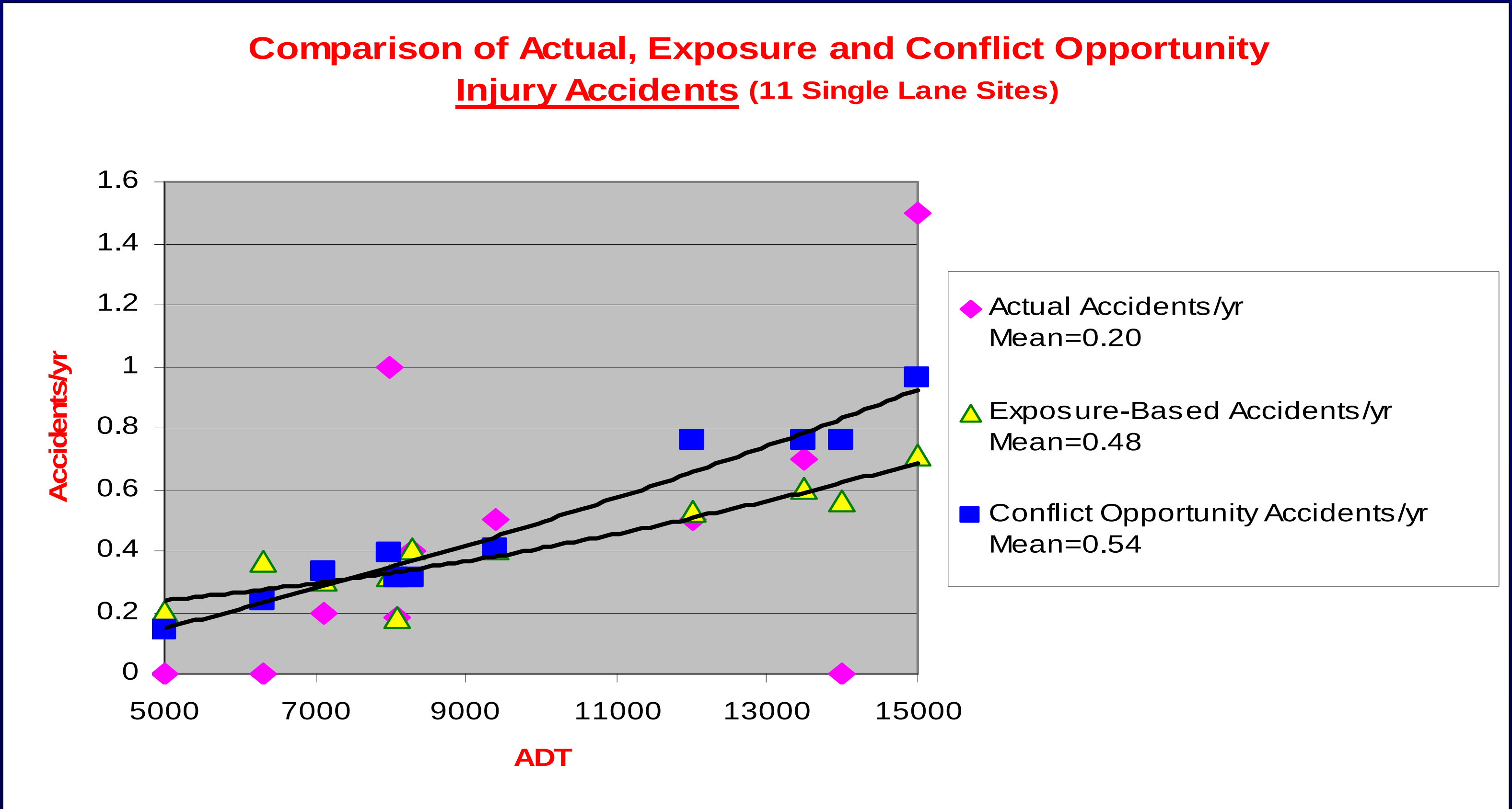
Single Lane Roundabout
Actual vs MDOT vs Conflict Opportunity
(for 11-MDOT single lane Roundabouts)



Also compare to FHWA Roundabout Guide (pg 112):
Average Single-Lane Roundabout = 2.4 Accidents/yr

Roundabout Injury Accident Validation

(for 11-MDOT Roundabouts)



Also compare to FHWA Roundabout Guide (pg 112):
Average Single-Lane Roundabout = 0.5 Injury Accidents/yr

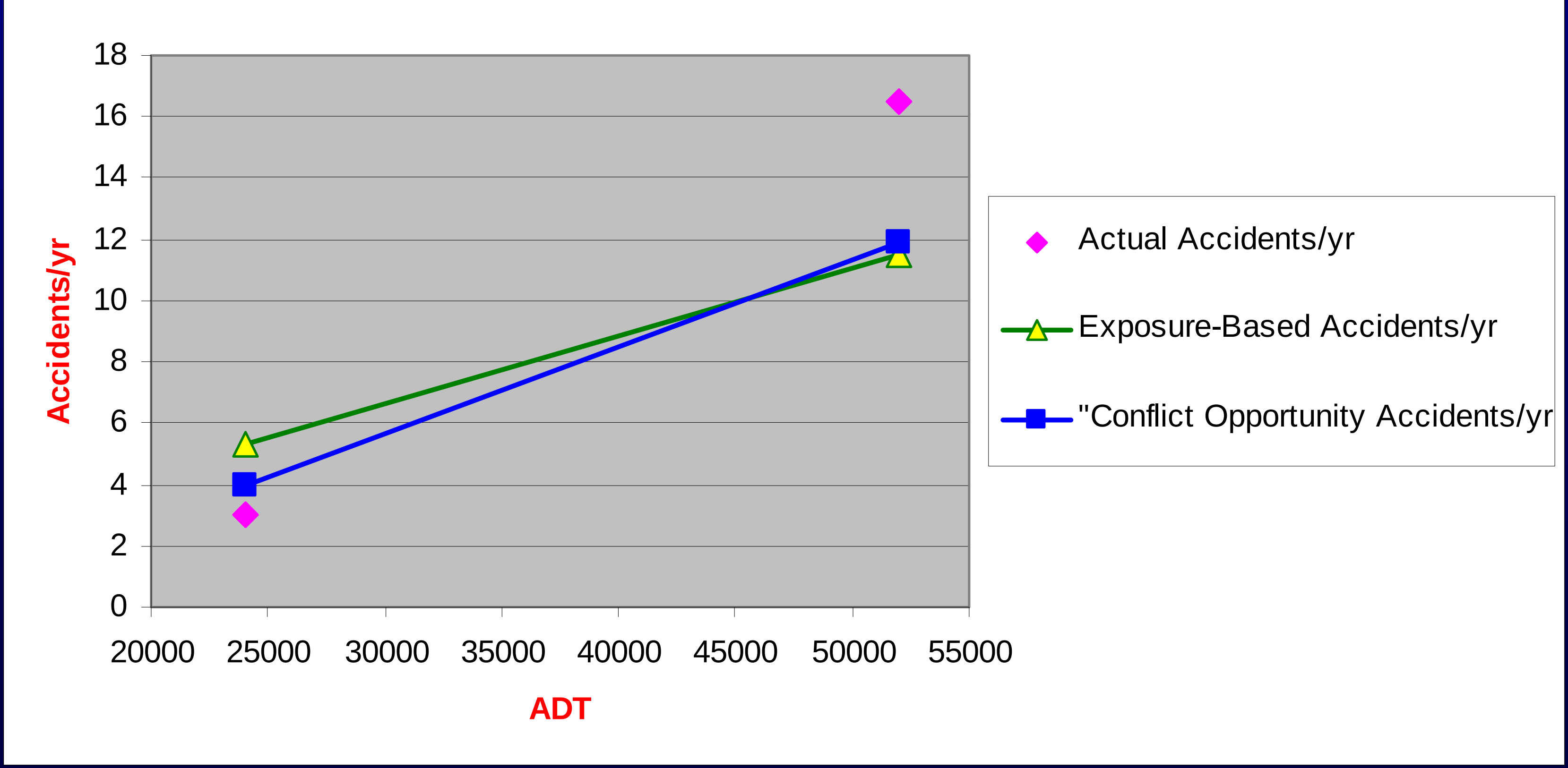
Roundabout Accident Type Validation

(for 11-MDOT Single lane Roundabouts)

Percentage Event Type	Conflict Opportunity Average from MDOT Data	Australia	Germany	Switzerland
Within Roundabout	55 (includes sideswipes)	51	30	46
Rear-End	15	18	28	13
Sideswipe	0	4 (within roundabout)	0	0
Single vehicle/ Fixed Object	30	18	17	35

Dual Roundabout Accident Validation

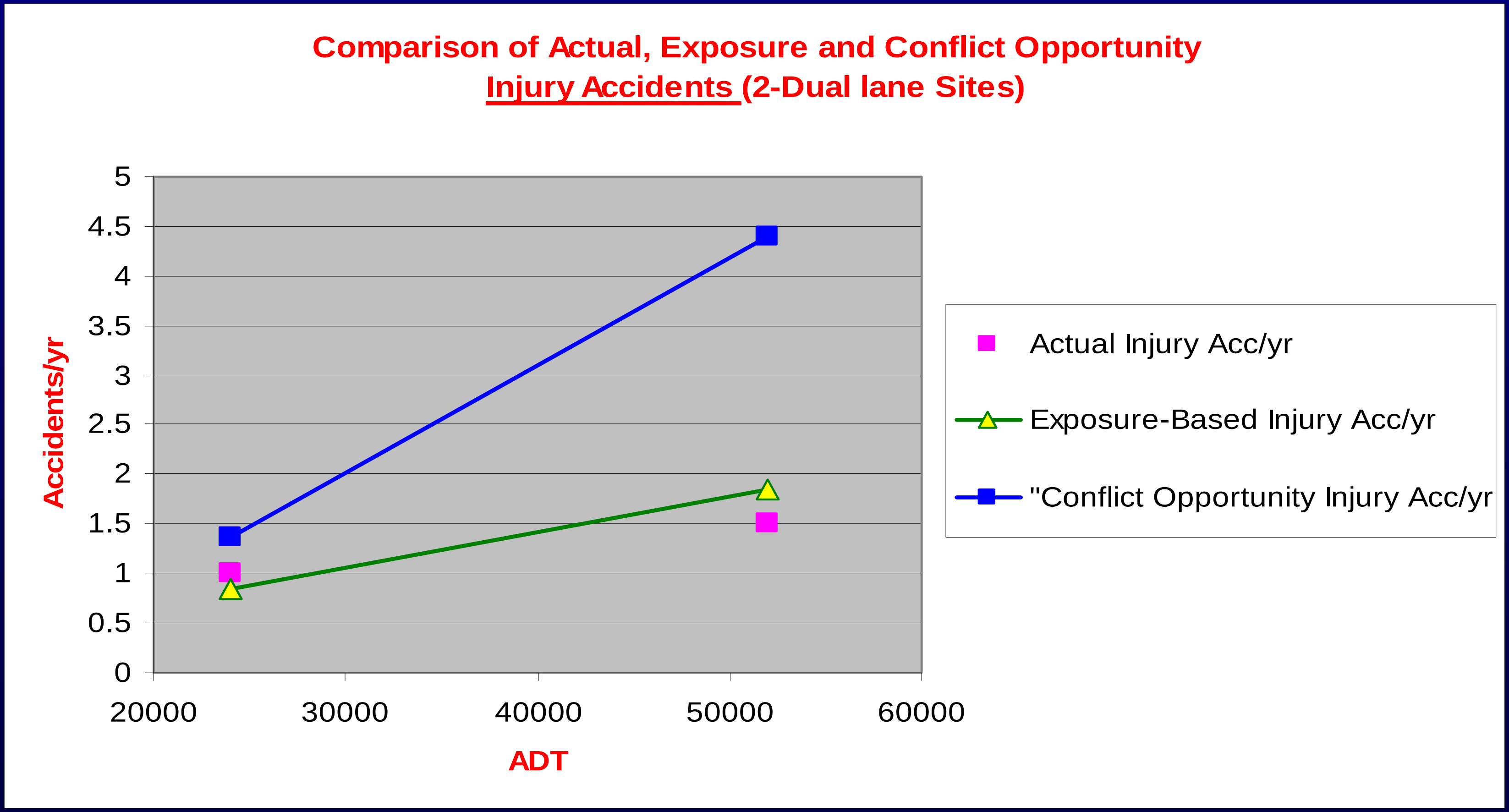
(for 2-MDOT Roundabouts)



Also compare to FHWA Roundabout Guide (pg 112):
Average Dual-Lane Roundabout = 15.3 Accidents/yr

Dual Roundabout Injury Accident Validation

(for 2-MDOT Roundabouts)



Also compare to FHWA Roundabout Guide (pg 112):
Average Dual-Lane Roundabout = 4.0 Injury Accidents/yr

In General
Conflict Opportunity Annual Accident Forecasts

1. Signalized Intersections -

- Over 80% accuracy (<1 STD) for 100 signalized intersections
- Angle & Rear-End Predictions within 15-20 percent of historical
- Total Accident Predictions within 10-15 percent of historical

2. Unsignalized Intersections (TWSC)

- Over 70% accuracy for 100 TWSC intersections

3. Roundabouts

- Over 80% accuracy compared to MDOT/FHWA averages

4. Overall -

Conflict Opportunity Technology offers annual accident estimates that are BETTER than ANY existing technology.

Transportation Research Record 1111 (Berg & Ha - 1995)

"The use of Opportunity-based accident measures will yield significantly different hazard rankings compared to conventional accident-rate expressions."

Well ok it works, but what seems like a "good idea" isn't necessarily a "safe idea"

So, how do you define something as "safe"?

SAFE or UNSAFE ?

Intersection Safety LOS

Quantity Thresholds (Upgrade Traffic Control Type from ITE)

DRIVEWAY > 1 in 3 Years (< 0.33/ Year)

YIELD > 2 in 3 Years (< 0.66/ Year)

2-Way STOP > 5 in 1 Year (MUTCD)

ALL- WAY / SIGNALS ??

Quality or Severity Thresholds

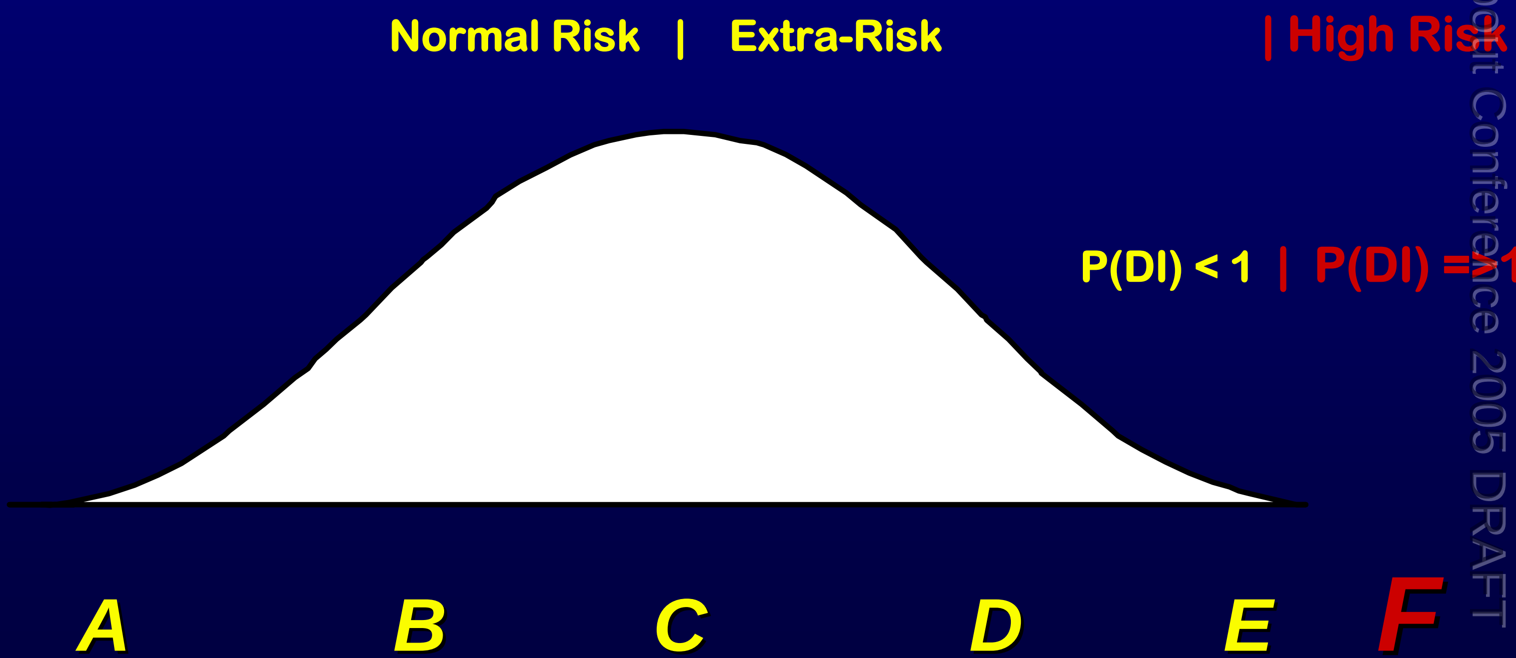
Injury-based Theoretical Guidance where

Lifetime Risk of Disabling Injury should be < 1.0 , thus where

Probability < 1.0 Normal or Extra-Risk Levels (Safety LOS A-E)

Probability > 1.0 High-Risk of Disabling Injury (Safety LOS F)

Intersection Severity Levels of Service
or
Probability of Disabling Auto Injury per Lifetime
(assume driving risk is normally distributed throughout lifetime)



How to Define Safety LOS E/F Threshold

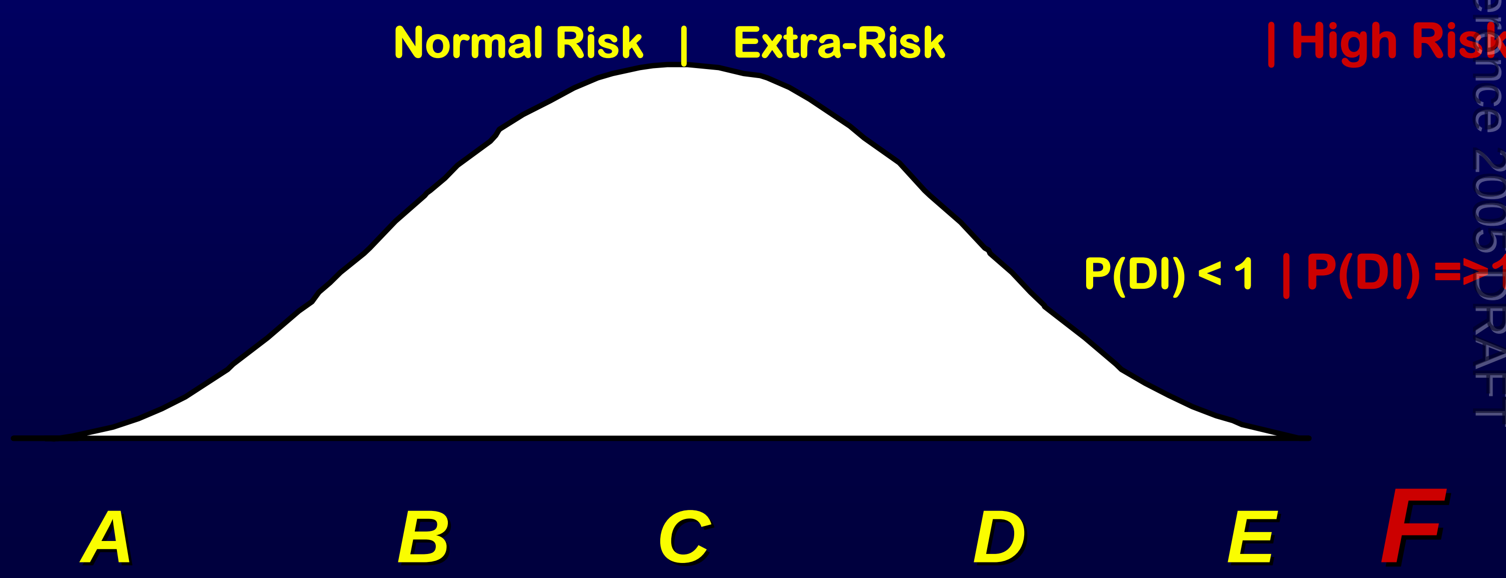
OSHA Standard Risk Threshold

The lifetime risk of death in any occupation should be less than 1 death in 1000 events

Using this guide, Ossenbruggen's FHWA analysis:

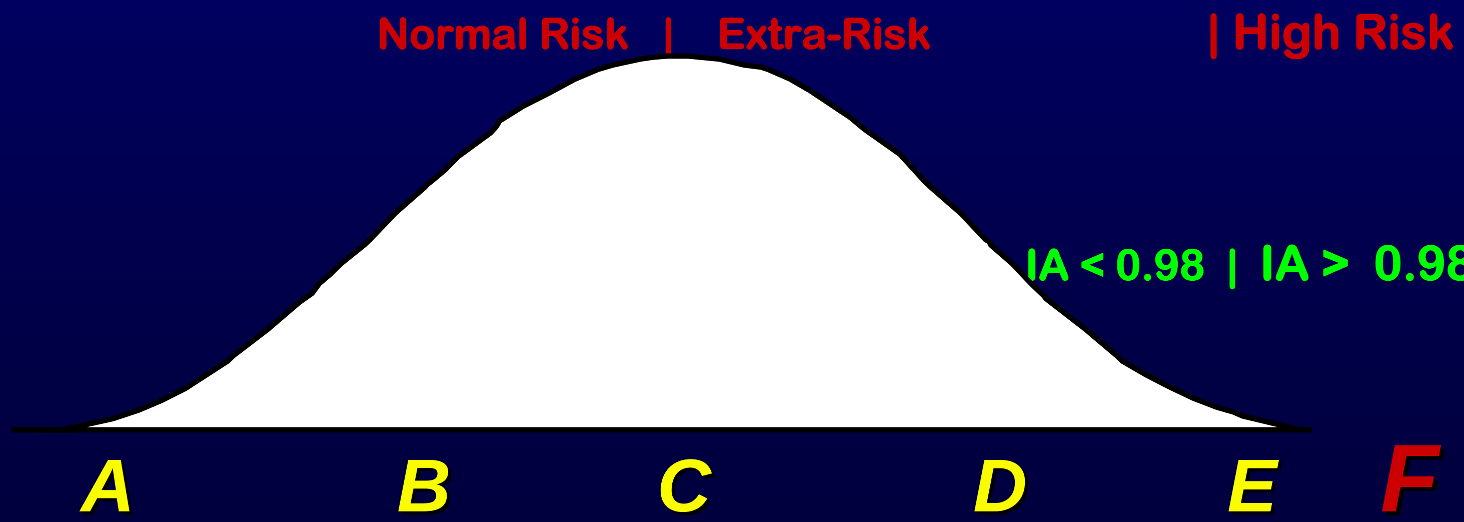
To achieve no more than 1 fatal accident in 1000 accidents, the number of injury accidents per year (which require professional treatment) should be less than about 7.8 / 10,000 ADT (entering an intersection).

(“A Method of Identifying Hazardous Highway Locations using the Principle of Individual Lifetime Risk” by P.J. Ossenbruggen in Risk, Health, Safety & Environment, 1998, pg. 90 and funded by FHWA)



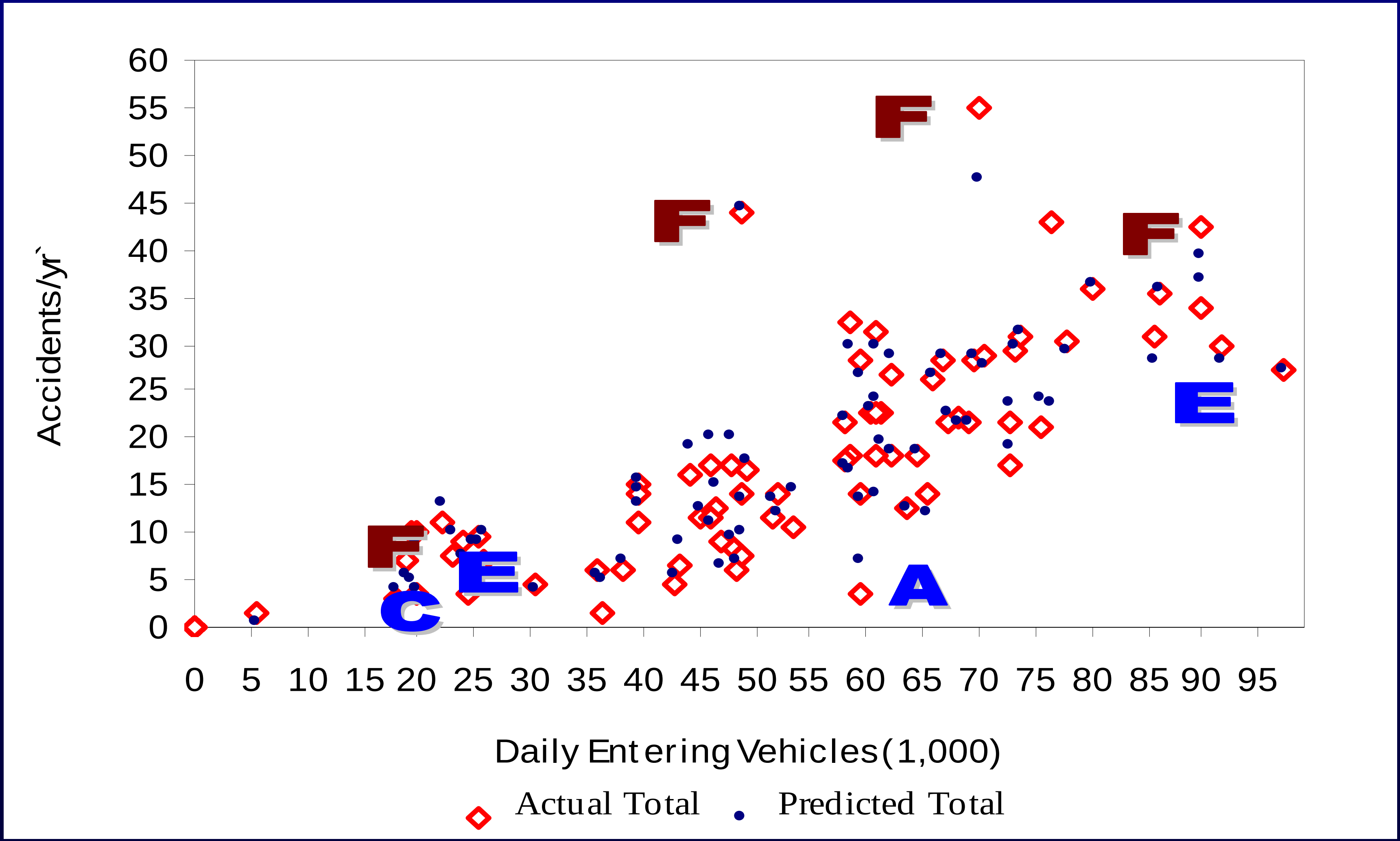
Define Safety LOS Example

7.8 Maximum Annual Injury accidents / 10,000 ADT (entering any intersection)
where 25% of all injury accidents occur at signal control
5% of all injury accidents at stop control
70% on all injury accidents at uncontrolled intersections/driveways
thus
Maximum Signalized Injury Threshold = 0.25 * 7.8 = < 2.0 Injury accidents-yr/10,000 ADT
Maximum Roundabout Injury Threshold = 50% of Signalized threshold (estimate)
Maximum Stop Control Injury Threshold = 20% of Signalized threshold
= 0.05 * 7.8 = < 0.40 Injury accidents-yr/10,000ADT
thus
for an urban 4-leg Stop control Intersection with 24,495 ADT
the Maximum Injury accidents < $\frac{24,495}{10,000}$ * 0.40 = < 0.98 IA/yr



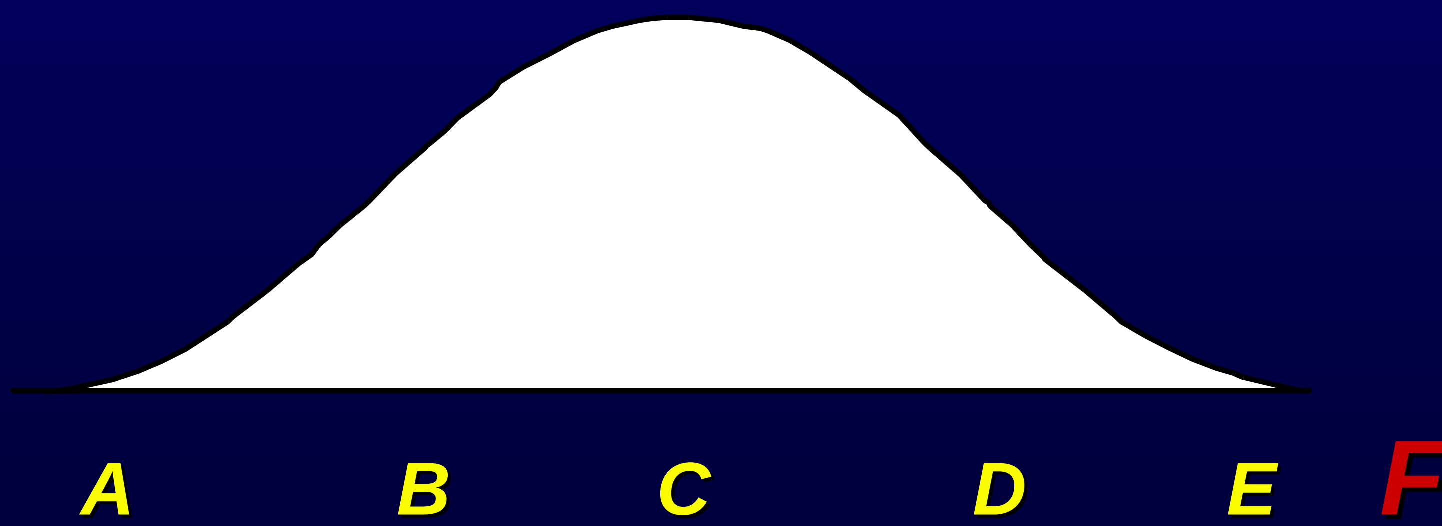
Intersection Injury-based Safety Levels of Service

(Northern Virginia Data)



Safe or Unsafe? Only Defined by Professionally Qualified Engineering Judgment

But as a guide
Safety LOS < D for Planning
Safety LOS < E for Operations
and
where Safety LOS = F exists ………….



<u>But what if the Safety LOS = F?</u>

1. **Warn the driver – MUTCD**

2. **Begin active correction, or**

3. **Begin Planning to improve the problem within a reasonable timeframe** (within TIP, or 3-5 year program),

4. **But the "Do Nothing" alternative is <u>NOT</u> acceptable.**

How does Conflict Opportunity analysis operate for Roundabouts?

<u>Answer</u>

Identical with an All-Way Stop control intersection <u>except</u> assume:

<u>Delay</u>

1. "Yield" not "Stop" Control - HCM 4.6 seconds / critical gap
2. No "Follow-up" gap - each gap acceptance is mutually exclusive
3. Right turn "bypass" lanes eliminate right-turns on the specific approach.

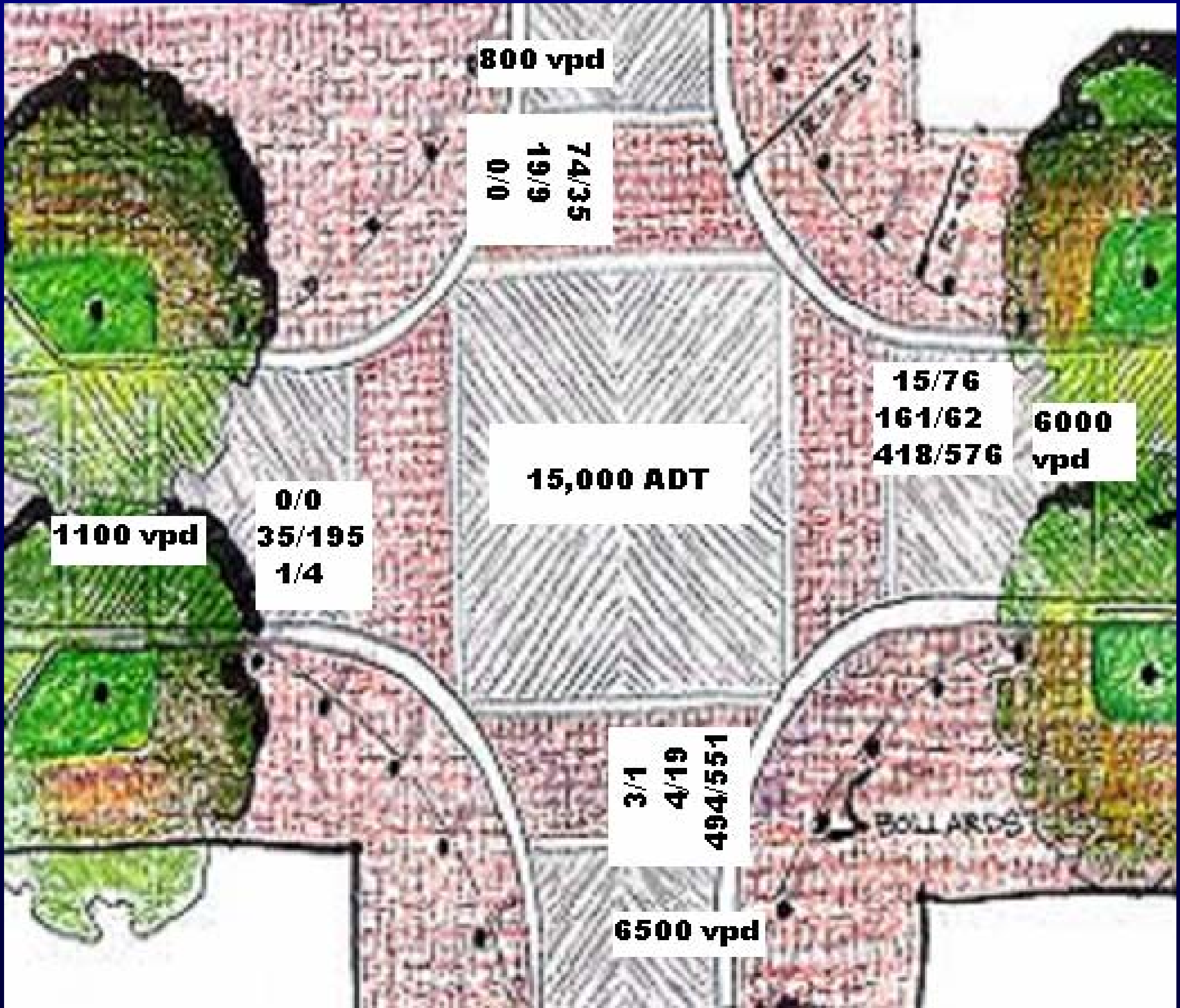
<u>Safety with Conflict Opportunities</u>

1. Frontal Angle conflicts identical to all-way stop except critical gap = "Yield"
2. Rear-end conflicts identical to all-way stop except gap = "Yield"
3. Sideswipe/Merge conflicts occur "within" single & dual lane roundabout but only on the "approach" to dual lane (similar to multi-lane all-way stop) + distance-based correction to conform to US roundabout accident history.
4. Fixed Object/Single Vehicle replaced by "low speed"exposure-based model
5. Right "Bypass" lanes eliminate right-turn conflicts on the specific approach.

So, you say you hate learning new computer software

Well, maybe it's not that bad…… Let's take a look

Example Project - Dulles Discovery Rezoning
Is a roundabout acceptable ?
How does Roundabout performance compare ?



CONFLICT OPPORTUNITY Safety Software

TRAF-Safe Micro Ver 4.0		Microscopic Conflict-Opportunity Estimate of Intersection Accidents, Injury, Safety LOS, Delay and Value	
INTERSECTION NAME >>	Major Roadway =	HISTORIC SULLY & TURLEY HALL RD.	SINGLE ROUNDABO 9/28/04 8:52 AM
Registration # 10001, Registration Valid ?	Y	Traffic Control	Study Hour = 18
Traffic Control with '2-WAY STOP'(Y)? =	N	= 'TWSC'	
Traffic Control with 'All-WAY STOP' (Y)? =	N	= 'AWSC'	
Traffic Control as Roundabout (Y)? =	Y	= 'Roundabout'	
Traffic Control with TRAFFIC SIGNAL (Y)? =	N	= 'Signalized'	
Annual Average Accidents & Injury		***Annual Average Accidents & Injury Accidents***	
Total Estimated Accidents per Year + Walk Bike =	2.4	= Total Accidents/Yr	
Total Accidents WITHIN Roundabout/Yr =	1.4	= Total Acc. WITHIN Rndabout/Yr	
Total Rear-End Approach Accidents per Year =	0.3	= Rear-End App. Acc./Yr	
Total Sideswipe Approach Accidents per Year =	0.0	= Sideswipe App. Acc./Yr	
Single Vehicle/Fixed Object Approach Accidents per Year =	0.8	= Single Veh. App. Acc/Yr	
TOTAL Injury Acc. per Year Including Walk Bike =	0.65	= Total Injury Acc./Yr	
Critical Vehicle+Walk Bike Injury Accidents/Yr =	0.03	= Critical Injury Acc./Yr	
Total Walk Bike Injury Accidents/5-Years =	0.00	= Walk Bike Injury Acc./5-Yrs	
Annual Average Accident Percent		***Annual Average Accident Percent***	
Total Accidents WITHIN Roundabout/Yr =	56%	= WITHIN Roundabout/Yr	
Total Rear-End Approach Accidents per Year =	13%	= Rear-End App. Acc./Yr	
Total Sideswipe Approach Accidents per Year =	0%	= Sideswipe App. Acc./Yr	
Single Vehicle/Fixed Object Approach Accidents per Year =	31%	= Single Veh. App. Acc/Yr	
Risk & Delay Summary		***Risk & Delay Summary***	
Safety Level of Service & Severity >	SAFETY LOS ='B'	'NORMAL RISK'	
Safety Planning Suggestions		*Safety Planning Suggestions*	
Safety Advisor =	ROUNDABOUT SAFETY LOOKS OK (SLOS <= 'E')		
Performance Index	133	*Performance Index*	
Annual Value of Risk on All Approaches (Value/Year) =	43,386	= Risk Value/Yr	
Annual Value of Delay on All Approaches (Value/Year) =	89,928	= Delay Value/Yr	
Approximate Intersection Delay (this hour)=	33.4	= Intersection Delay (s/V)	
Hcm Intersection Delay Level of Service (this hour) =	HCM LOS 'D'	= Hcm 2000 LOS	

TS Micro Operation
1. Select Control Device
2. Input Traffic
3. Input Geometry/Speed
4. Input Signal Data
5. SELECT "Run 24 Hours"

Intelligent Traffic Safety Software ITS² for the 21st Century

Registered to: Specify User

Traf-Safe is a probability-based traffic engineering tool to analize both existing intersection safety and delay and to forecast accidents, injuries and delay with remarkable fidelity. Based on original General Motors "conflict opportunity" research, TRAF-Safe builds on GM's probability models with the aid of modern software to create a safety model so unique it was granted a US Patent. Whether for Traffic Planning, Development Impact Studies, Safety Audits, or Expert Witness, TRAF-Safe provides over 80% accuracy predicting annual accidents at unsignalized or signalized intersections. Traffic control can be two-way stop, all-way stop, single or dual roundabout, or fully protected/permissive actuated signals in progressive corridors with any combination of speed, geometry, or turning movements and even with an injury forecast for walk bike trips. Today, your doctor relies on magnetic imaging to protect your health and your dentist relies on on x-rays, and like them your traffic safety studies deserve the accuracy, lack of bias, and documentation of TRAF-Safe Software.

LICENSED TO:
Specify Employer, City, USA

DAILY VOLUME REVIEW	HISTORIC SULLY	TURLEY HALL RD.
Total Vehicles Entering Intersection per Day =	14,476	= 2-WAY ADT
Vehicles Entering from Major Approaches per Day =	7,154	=MAJOR ADT Entering
Vehicles Entering from Minor Approaches per Day =	7,323	=MINOR ADT Entering
Vehicles Entering in the 'Study Hour' (vph) =	1,528	= This Hour Volume
Average 'Hour/Daily Ratio or k Factor' this Study Hour =	0.086	= Ave.'K' Factor

Run 24 Hours

National Roundabout Conference 2005 DRAFT

What are the Inputs ?

Input AM & PM Volume by Lane

(other hours automatically interpolated)

Estimated Hourly Turning Movements from Am and/or Pm Peak Data or Input Daily Turning Movements HISTORIC SULLY & TURLEY HALL RD. 9/28/04 9:30 AM

ENDING Hour	Protected LT: Y				Protected LT: Y				Protected LT: Y				Protected LT Y				HOURLY VOLUME
	Protected RT: N HISTORIC SULLY			Approach 1	Protected RT: N TURLEY HALL RD.			Approach 2	Protected RT: N HISTORIC SULLY			Approach 3	Protected RT: N TURLEY HALL RD.			Approach 4	
	EB Left	EB Thru	EB Right	Walk-Bike	NB Left	NB Thru	NB Right	Walk-Bike	WB Left	WB Thru	WB Right	Walk-Bike	SB Left	SB Thru	SB Right	Walk-Bike	
12-1 AM	0	5	0	0	0	1	38	0	14	2	2	0	2	1	0	0	65
1-2	0	1	0	0	0	2	25	0	8	3	0	0	4	2	0	0	45
2-3	0	1	0	0	0	1	16	0	6	2	0	0	2	1	0	0	31
3-4	0	1	0	0	0	1	20	0	9	4	0	0	3	1	0	0	39
4-5	0	2	0	0	0	1	35	0	19	7	0	0	5	1	0	0	71
5-6	0	7	0	0	0	1	135	0	84	32	3	0	20	5	0	0	288
6-7	0	19	0	0	2	3	311	0	227	87	8	0	47	12	0	0	716
7-8	**0**	**35**	**1**	0	**3**	**4**	**494**	0	**418**	**161**	**15**	0	**74**	**19**	**0**	0	1224
8-9	0	24	0	0	2	3	390	0	283	109	10	0	58	15	0	0	895
9-10	0	16	0	0	2	2	307	0	192	74	7	0	46	12	0	0	659
10-11	0	11	0	0	1	2	244	0	131	50	5	0	36	9	0	0	490
11-12	0	11	0	0	2	2	278	0	128	49	5	0	42	11	0	0	527
12-1 PM	0	73	1	0	0	15	435	0	214	23	28	0	28	7	0	0	825
1-2	0	83	2	0	0	15	431	0	246	27	33	0	27	7	0	0	871
2-3	0	90	2	0	0	14	399	0	266	29	35	0	25	7	0	0	866
3-4	0	118	2	0	0	16	451	0	348	37	46	0	29	7	0	0	1054
4-5	0	152	3	0	0	17	498	0	448	48	59	0	32	8	0	0	1265
5-6	**0**	**195**	**4**	0	**1**	**19**	**551**	0	**576**	**62**	**76**	0	**35**	**9**	**0**	0	1528
6-7	0	138	3	0	0	16	455	0	409	44	54	0	29	7	0	0	1154
7-8	0	79	2	0	0	10	303	0	234	25	31	0	19	5	0	0	709
8-9	0	47	1	0	0	7	209	0	139	15	18	0	13	3	0	0	454
9-10	0	34	0	0	0	6	176	0	101	11	13	0	11	3	0	0	356
10-11	0	20	0	0	0	4	118	0	58	6	8	0	8	2	0	0	224
11-12	0	10	0	0	0	2	68	0	29	3	4	0	4	1	0	0	121
	Left Turn	Through	Right Turn		Left Turn	Through	Right Turn		Left Turn	Through	Right Turn		Left Turn	Through	Right Turn		14,476
	0	1171	21		13	165	6388		4590	912	459		600	156	0		TOTAL
DAILY TOTAL	Approach=	1192			Approach=	6566			Approach=	5961			Approach=	756			
Percent	0%	98%	2%	0	0%	3%	97%	0	77%	15%	8%	0	79%	21%	0%	0	
	MAJOR APPROACH #1			Walk-Bike	MINOR APPROACH #2			Walk-Bike	MAJOR APPROACH #3			Walk-Bike	MAJOR APPROACH #4			Walk-Bike	

Input Geometry by Approach

Geometry, Speed & Other Input and Volume Output Summary

SINGLE ROUNDABOUT — 9/28/04 8:53 AM

Traffic Distribution Type =	URBAN
Use AM & PM Peak Volume Input with Interpolation?=	Y
Use Default Peak to Daily Ratio =	N
Default 'Peak to Daily Ratio' Approach 1&3=	0.100
Default 'Peak to Daily Ratio' Approach 2&4=	0.100
Use Separate Weekend Analysis =	N
Approach 1&3 ADT Adjustment=	0.86
Approach 2&4 ADT Adjustment=	1.00
Urban Area Population(1,000) =	150
Walk-Bike Distribution CBD or Urban =	URBAN

MINOR 4

2-Way Volume (vph): 1,381

TURLEY HALL RD.

Speed(mph)=	20	12	=App. Width
Left Bay =	N	N	=RIGHT BYPASS
Lt. Bay Storage=	0	0	=Rt. Bay Storage
Dual Lefts =	N	0	=% Trucks
Median Width=	0	0	=DownGrade(%)
Actual W-B/Day=	0	0	=Rt.Accel. Length
Latent W-B/Day=	131	N	=Rt. Turn+Island
		N	=Coordinated Cooridor

Inbound	Outbound
756	624

< Right	Thru	Left >
0	156	600

MAJOR 1

2,118 2-Way

<Outbound	926
Inbound>	1192

Name = HISTORIC SULLY

Left =	0
Thru >=	1171
Right =	21

Roundabout	Roundabout
35	35
35	35
Roundabout	Roundabout

Speed(mph)=	20	12	=App. Width
Left Bay =	N	N	=RIGHT BYPASS
Lt. Bay Storage=	0	0	=Rt. Bay Storage
Dual Lefts =	N	0	=% Trucks
Median Width=	0	0	=DownGrade(%)
Actual W-B/Day=	0	0	=Rt.Accel. Length
Latent W-B/Day=	17	N	=Rt. Turn+Island
		N	=Coordinated Cooridor

MAJOR 3

Speed(mph) =	20	12	=App. Width
Left Bay =	N	N	=RIGHT BYPASS
Lt. Bay Storage=	0	0	=Rt. Bay Storage
Dual Lefts =	N	0	=% Trucks
Median Width=	0	0	=DownGrade(%)
Actual W-B/Day=	0	0	=Rt.Accel. Length
Latent W-B/Day=	144	N	=Rt. Turn+Island
		N	=Coordinated Cooridor

459	= Right
912	=< Thru
4590	= Left

HISTORIC SULLY = Name

5961	<Inbound
8159	Outbound>

14,121 2-Way

MINOR 2

< Left	Thru ^	Right >
13	165	6388

Outbound	Inbound
4767	6566

Speed(mph)=	20	12	=App. Width
Left Bay =	N	N	=RIGHT BYPASS
Lt. Bay Storage=	0	0	=Rt. Bay Storage
Dual Lefts =	N	0	=% Trucks
Median Width=	0	0	=DownGrade(%)
Actual W-B/Day=	0	0	=Rt.Accel. Length
Latent W-B/Day=	26	N	=Rt. Turn+Island
		N	=Coordinated Cooridor

Name= TURLEY HALL RD.

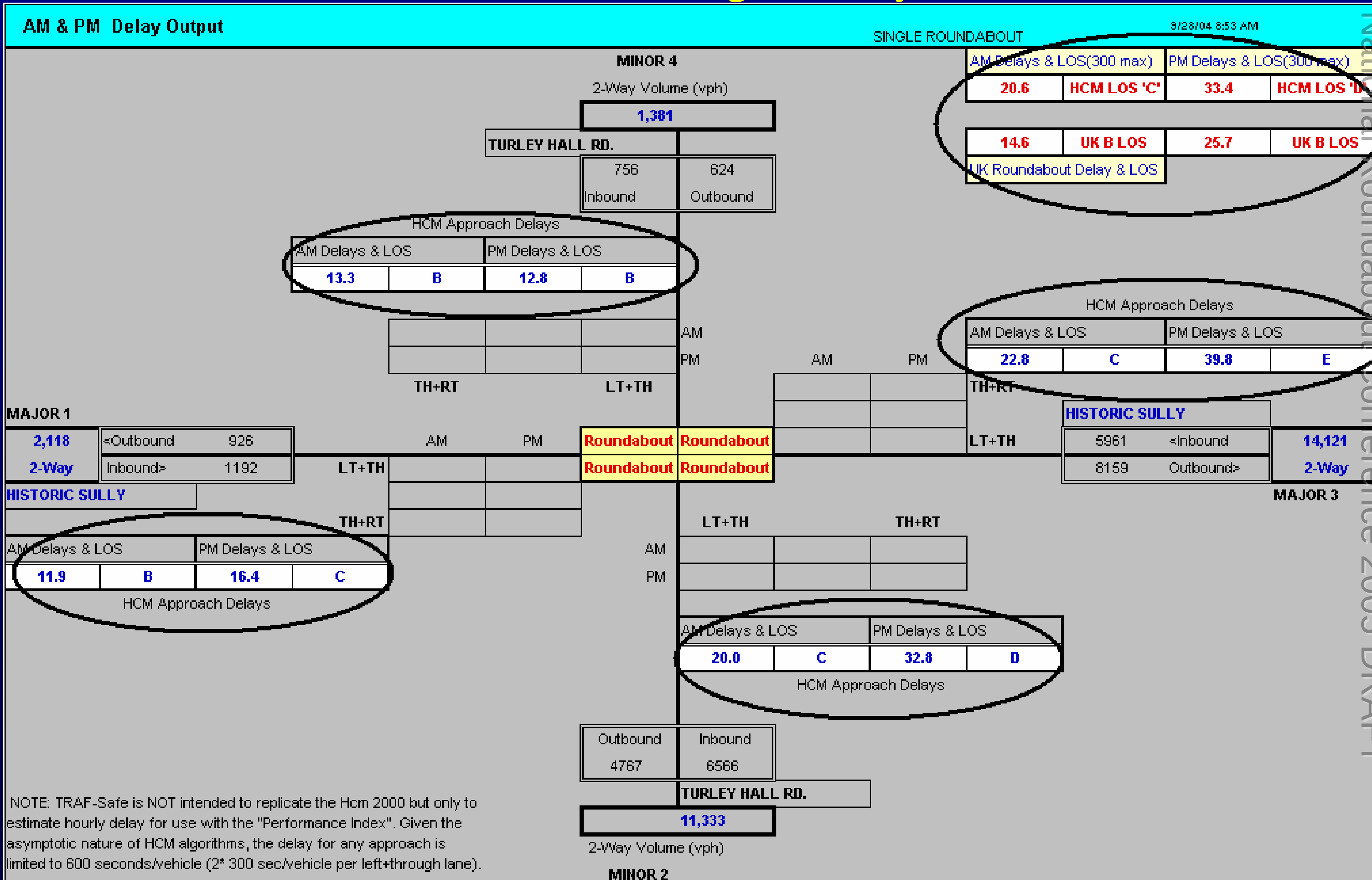
2-Way Volume (vph): 11,333

MINOR 2

ROUNDABOUT INPUTS — SPEED = 21.1

Inscribed D(ft)= 100		Note: Nu	Central D(ft)= 70
Urban-Mini	Urban-Compa	Urban-Single	Urban-Dual
15 mph, 11 ft.	15 mph, 11 ft	20 mph, 12 ft	20 mph operating, 24 ft.
InsD = 45-80 ft.	InsD=80-100	InsD=100-13	InDia=150-180; C.Isl = ID-60 ft.
C.Isl=26 ft.	C.Isl=28 ft.	C.Isl=30 ft.	

Check Delay Output



Check Queuing Output

Left Bay and Through Queue length (feet)			HISTORIC SULLY		TURLEY HALL RD.		SINGLE ROUNDABC	9/28/04 8:52 AM
Percentile =	98	70	98	70	98	70	98	70
	Approach 1		Approach 2		Approach 3		Approach 4	
HOUR	Thru Lane Queue	Thru Lane Queue	Thru Lane Appr. 2	Thru Lane Queue	Thru Lane Appr. 3	Thru Lane Queue	Thru Lane Appr. 4	Thru Lane Queue
1	0	1	0	2	0	1	0	0
2	0	0	0	2	0	1	0	0
3	0	0	0	1	0	1	0	0
4	0	0	0	1	0	1	0	0
5	0	0	0	2	0	2	0	1
6	0	1	0	8	0	7	0	1
7	0	1	0	24	0	23	0	2
8	0	3	0	59	0	79	0	4
9	0	2	0	35	0	33	0	3
10	0	1	0	23	0	18	0	2
11	0	1	0	17	0	11	0	1
12	0	1	0	20	0	11	0	2
13	0	5	0	46	0	18	0	1
14	0	6	0	46	0	22	0	1
15	0	6	0	39	0	24	0	1
16	0	9	0	53	0	38	0	1
17	0	13	0	71	0	67	0	2
18	0	20	0	106	0	153	0	2
19	0	11	0	55	0	53	0	1
20	0	5	0	24	0	20	0	1
21	0	3	0	14	0	10	0	1
22	0	2	0	11	0	7	0	1
23	0	1	0	7	0	4	0	1
24	0	1	0	4	0	2	0	0
MAX QUEUE (ft) =	0	20	0	106	0	153	0	4

If Signals - Input HCM-based Signal Data

SIGNAL INPUT	MAJOR ROADWAY	MINOR ROADWAY	COMMENTS	9/3/04 12:03 PM

Signal Timing Selection 'Traf-Safe' or 'Actual' =	TRAF-SAFE	= Traf-Safe or Actual
Controller Actuated or Pretimed =	ACTUATED	= Actuated or Pretimed
Traf-Safe Delay Analysis for each hour? =	YES	= Traf-Safe Delay?
Hourly Delay Analysis with Input of Delays ? =	NO	= Input Delay Analysis
Number of Phases (2,3, or 4) This Hour =	3	= Phases This Hour
Approximate CYCLE Time(sec) =	53	= TRAF-Safe Cycle (sec)
Effective Through Green Approach 1 & 3 (sec) =	37	= Critical Lt+Th 1 or 3
Effective Through Green Approach 2 & 4 (sec) =	10	= Critical Lt+Th 2 or 4
Intersection Control Delay (seconds/vehicle) =	14	= INTERSECTION DELAY

Approach Delay (1-4)
13
20
13
19

Study Hour = 18

Common All-Red Left (sec)=	Y	1.0
Common All-Red Thru (sec)=	Y	2.0
Lost Time/Phase =		2.0
Unit Extension =		1.0

	LT MIN INITIAL
LT Approach 1 =	7.0
LT Approach 2 =	0.0
LT Approach 3 =	7.0
LT Approach 4 =	0.0

	THRU MIN INITIAL
THRU Approach 1 =	12.0
THRU Approach 2 =	7.0
THRU Approach 3 =	12.0
THRU Approach 4 =	7.0

Left and Right Turn Characteristics	Protected LT Phase+Bay?	Permitted LT ?	Dual?
Left Turns from Approach # 1 =	Y	N	N
Left Turns from Approach # 2 =	N	Y	N
Left Turns from Approach # 3 =	Y	N	N
Left Turns from Approach # 4 =	N	Y	N

	Protected LT (s)	Sneakers (v/h)
Left Turns from Approach # 1 =	10	2
Left Turns from Approach # 2 =	0	1
Left Turns from Approach # 3 =	10	2
Left Turns from Approach # 4 =	0	1

	Saturation Flow (v/h)	Rt. Turn-on-Red
Left and Right Turns from Approach # 1 =	1905	7
Left and Right Turns from Approach # 2 =	1905	5
Left and Right Turns from Approach # 3 =	1905	7
Left and Right Turns from Approach # 4 =	1905	5

Additional Input by Approach	Approach # 1	Approach # 2
TRAF-Safe/Hcm Arrival Type=	1.4	1.3
Parking per Hour =	0	0
Buses per Hour =	0	0
Approach DownGrade % =	0	0
Pedestrians per this Hour =	0	0
Pedestrian Button + Phase ? =	N	N

Additional Input by Approach	Approach # 3	Approach # 4
TRAF-Safe/Hcm Arrival Type=	1.4	1.4
Parking per Hour =	0	0
Buses per Hour =	0	0
Approach DownGrade % =	0	0
Pedestrians per this Hour =	0	0
Pedestrian Button + Phase ? =	N	N

Timing Summary	Am Peak	Mid-Day	Pm Peak	Off-Peak
Begin Time =	6	9	16	20
End Time =	9	16	20	6
Max Cycle Length =	53	51	53	51
Phases =	3	3	3	3
Progression Active =	N	N	N	N
Progressive Cycle Length=	180	130	180	120
Appr.1 (NEMA 5) Left =	10	10	10	10
Appr.2 (NEMA 7) Left =	0	0	0	0
Appr.3 (NEMA 1) Left =	10	10	10	10
Appr.4 (NEMA 3) Left =	0	0	0	0
Approach1 (NEMA 2) =	27	25	27	25
Approach3 (NEMA 6) =	27	25	27	25
Overlap Throughs and Lefts =	Y		Split Phase 1&3? =	N
Approach 2 (NEMA 4) =	10	10	10	10
Approach 4 (NEMA 8) =	10	10	10	10
Overlap Throughs and Lefts =	N		Split Phase 2&4? =	N

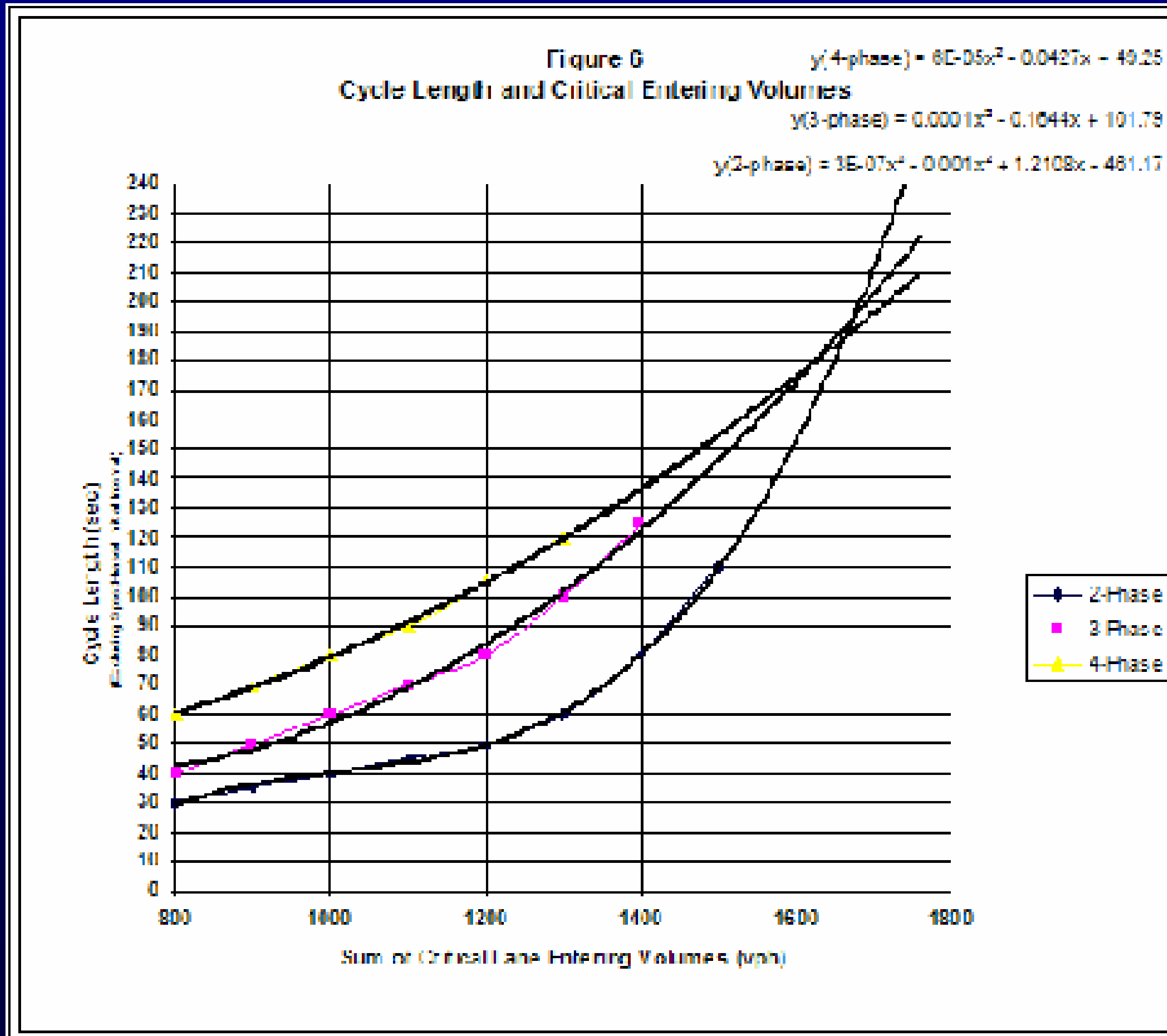
Max LT Queues	Approach 1 LT	Approach 2 LT	Approach 3 LT	Approach 4 LT
	48	0	46	0

Internal Signal Timing - based on ICU Concepts

CM 2000 Cycle & Split Selector			1.00								Study Hour = 18	
Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lanes	1	2	0	1	2	0	0	2	0	0	2	0
SHARED LT Lane ?? (y=1/n=0)	0			0			1			1		
Volume	130	1126	70	130	1126	70	50	232	50	50	232	50
Peak Hour Factor	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Pedestrians	0		0	0		0	0		0	0		0
Ped Button (y=1/n=0)	WLK	0	FDNW	WLK	0	FDNW	WLK	0	FDNW	WLK	0	FDNW
Pedestrian Timing Required	0.0	0.0	12.0	0.0	0.0	12.0	0.0	0.0	18.0	0.0	0.0	18.0
Free Right (y=1/n=0)			0			0			0			0
Ideal Flow	1905	1900	1905	1905	1900	1905	1905	1900	1905	1905	1900	1905
Lost Time	0	2	0	0	2	0	0	2	0	0	2	0
Phases & Corridor Cycle Length	Phases= 3.0		Maximum Cycle Length = 300									
Preliminary Cycle Estimate =	50		SumCriticalVolumes =	869	2-Phase =	50	3-Phase =	50	4-Phase = 60			

Adjusted Volume	130	1126	70	130	1126	70	50	232	50	50	232	50
Volume Combined	130	1196	0	130	1196	0	0	332	0	0	332	0
Volume Separate Left or Right	130	1196	0	130	1196	0	0	282	0	0	282	0
Lane Utilization Factor	1.000	0.952	1.000	1.000	0.952	1.000	1.000	0.952	1.000	1.000	0.952	1.000
Turning Factor Adjust	0.95	0.99	0.85	0.95	0.99	0.85	0.95	0.97	0.85	0.95	0.97	0.85
Saturated Flow Combined	1810	3586	0	1810	3586	0	0	3509	0	0	3509	0
Saturated Flow Separate	1810	3586	0	1810	3586	0	1810	3521	0	1810	3521	0
minimum initial	7.0	12.0	0.00	7.0	12.0	0.00	0.0	7.0	0.00	0.0	7.0	0.00
minimum split	8.0	13.0	0.00	8.0	13.0	0.00	1.0	8.0	0.00	1.0	8.0	0.00
Yellow time	3.00	4.50	0.00	3.00	4.50	0.00	3.00	3.50	0.00	3.00	3.50	0.00
All-red	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00	0.00
Extension	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Recall	None	Min	None	None	Min	None	None	None	None	None	None	None
Minimum Green	7	13	0	7	13	0	0	8	0	0	8	0
Ped/Bike Interference Time	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hcm LT Adjust / Ped/Bike Frequency	100.0%		0.0%	100.0%		0.0%	100.0%		0.0%	100.0%		0.0%

With Automatic NCHRP/Practical Cycle Length



with Protected, Permitted or Split phase automatically selected for each hour of the day

PROTECTED	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Protected Option Allowed (1=Yes,0=No)		1			1			0			0	
Reference Time	3.6	16.7	0.0	3.6	16.7	0.0	NA	0.0	0.0	NA	0.0	0.0
Actuated effetive green	10.0	23.2	0.0	10.0	23.2	0.0	3.0	3.5	0.0	3.0	3.5	0.0
Adjusted to Hour Act.Eff.Green	10.0	26.8	0.00	10.0	26.8	0.00	3.0	3.5	0.00	3.0	3.5	0.00
Hourly actuated g/c	0.20	0.54	0.00	0.20	0.54	0.00	0.06	0.07	0.00	0.06	0.07	0.00

PERMITTED	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Permitted Option Allowed (1=Yes, 0=No)		0	Permissive 1&3=	NO	0			1	Permissive 2&4=	YES	1	
Adjusted Saturation A		3586			3586			2348			2348	
Reference Time A		NA			NA			6.0			6.0	
Adjusted Saturation B		3586			3586			1761			1761	
Reference Time B		NA			NA			NA			NA	
Reference Time Lefts	11.6		NA	11.6		NA	0.0		0.0	0.0		0.0
Reference Time		NA			NA			6.0			6.0	
Adjusted Reference Time		0.0			0.0			10.0			10.0	
Actuated effetive green	11.6	11.6	NA	11.6	11.6	NA	0.0	10.0	0.00	0.0	10.0	0.00
Adjusted to Hour Act.Eff.Green	11.6	13.4	0.00	11.6	13.4	0.00	0.0	10.0	0.00	0.0	10.0	0.00
Hourly actuated g/c	0.23	0.27	0.00	0.23	0.27	0.00	0.00	0.20	0.00	0.00	0.20	0.00

SPLIT	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Split Timing			SPLIT APP 1&3=	NO					SPLIT APP 2&4=	NO		
Ref Time Combined		16.7			16.7			4.7			4.7	
Ref Time By Movement	3.6	16.7		3.6	16.7		0.0	4.0		0.0	4.0	
Reference Time		16.7			16.7			4.7			4.7	
Adjusted Reference Time	18.7	18.7		18.7	18.7		10.0	10.0		10.0	10.0	
Actuated effetive green	3.6	18.7	18.7	3.6	18.7	18.7	10.0	10.0	10.0	10.0	10.0	10.0
Adjusted to Hour Act.Eff.Green	3.6	21.6	0.0	3.6	21.6	0.0	10.0	10.0	0.0	10.0	10.0	0.0
Hourly actuated g/c	0.07	0.43	0.00	0.07	0.43	0.00	0.20	0.20	0.00	0.20	0.20	0.00

Check Peak Hour Signal Output

Hour= **18** 9/28/04 9:52 AM

Controller Type=	HISTORIC SULLY			TURLEY HALL RD.			HISTORIC SULLY			TURLEY HALL RD.		
ACTUATED	Approach 1 LT	Approach 1 Thr	Approach 1 RT	Approach 2 LT	Approach 2 Thr	Approach 2 RT	Approach 3 LT	Approach 3 Thr	Approach 3 RT	Approach 4 LT	Approach 4 Thr	Approach 4 RT
LT Turn Type	Prot/Perm			Prot/Perm			Prot/Perm			Prot/Perm		
LT Sneakers/Hr	54			54			161			65		
Right-on-Red			0			54			7			0
Ideal Flow	1900	3800	1900	1900	3800	1900	1900	3800	1900	1900	3800	1900
Lane Width Adjust	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Heavy Vehicle %	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Heavy Vehicle Adjust	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Grade adjust	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Parking Adjust	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bus Blockage	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Area Type	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Lane Utilization	1.00	0.95	1.00	1.00	0.95	1.00	1.00	0.95	1.00	1.00	0.95	1.00
Flt	0.95			0.95			0.59			0.29		
Frt			1.00			0.85			0.98			1.00
Ped/Bike Adjust Lt&Rt	1.00		1.00	1.00		1.00	1.00		1.00	1.00		1.00
Sat. Flow Lt Perm	0			0			1069			526		
Sat. Flow Lt Prot	0			0			1810			1810		
Sat Flow Thru		3607			3618			3560			3617	
Sat Flow Rt			0			1619			0			0
Lane Group Flow (vph)	0	199	0	1	19	497	576	131	0	35	9	0
Walk/Bike Calls per Hour			0			0			0			0
	WLK	Total Time	FDNW	WLK	Total Time	FDNW	WLK	Total Time	FDNW	WLK	Total Time	FDNW
Pedestrian Timing (s)	0.0	0.0	21.0	0.0	0.0	18.0	0.0	0.0	21.0	0.0	0.0	18.0
minimum initial	7.0	12.0	0.0	7.0	7.0	7.0	7.0	12.0	0.0	7.0	7.0	7.0
minimum split	8.0	13.0	0.0	8.0	8.0	8.0	8.0	13.0	0.0	8.0	8.0	0.0
Yellow time	3.0	3.5	0.0	3.0	3.5	3.5	3.0	3.5	0.0	3.0	3.5	0.0
All-red	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	0.0	1.0	1.0	0.0
Extension	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Recall	None	Min	None	None	None	None	None	Min	None	None	None	None
Minimum Green	7.0	13.0	0.0	7.0	8.0	7.0	7.0	13.0	0.0	7.0	8.0	7.0
Ped/Bike Interference(s)		0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0
Ped/Bike Frequency		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00
Actuated Green (sec)	9.4	16.2	0.0	9.4	12.6	19.1	20.7	16.2	0.0	9.4	12.6	12.6
Actuated Green (g/c)	14%	24%	0%	14%	19%	29%	31%	24%	0%	14%	19%	19%
Lane group capacity	54	874	1600	54	683	1603	980	863	1600	418	683	1600
v/s Ratio	0.00	0.06	0.00	0.00	0.01	0.31	0.32	0.04	0.00	0.02	0.00	0.00
V/C Ratio	0.00	0.23	0.00	0.02	0.03	0.31	0.59	0.15	0.00	0.08	0.01	0.00
Uniform Delay D1	0.0	20.3	0.0	0.0	22.1	0.0	4.3	19.9	0.0	9.7	22.1	0.0
Progression factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Incremental delay D2	0.0	0.6	0.0	0.0	0.1	0.5	2.6	0.4	0.0	0.4	0.0	0.0
Delay (sec)	0.0	20.9	0.0	0.0	22.2	0.5	6.9	20.3	0.0	10.0	22.1	0.0
Level of Service	A	C		A	C		A	C		B	C	
Approach Delay (sec)		**21**			**21**			**8**			**12**	
Approach LOS		**C**			**C**			**A**			**B**	
HCM Control Delay	**15**	**Intersection LOS =**										
Cycle length Used	**67**	**B HCM LOS**										
Actuated Cycle Length	**64**											

Check Hourly Signal Output Throughout Day
Cycle, Phase (thru+turn) & Splits

Daily Timing Summary MAJOR ROADWAY MINOR ROADWAY COMMENTS 9/3/04 12:03 PM 18

	1 & 3 Phasing	App. 1 Left	App. 1 Thru	App. 3 Left	App. 3 Thru	2 & 4 Phasing	App. 2 Left	App. 2 Thru	App. 4 Left	App. 4 Thru	Cycle	DELAY
AM												
5-6Am Hour 6	Prot	10	25	10	25	LtPerm	0	10	0	10	51	10
6-7 Hour 7	Prot	10	25	10	25	LtPerm	0	10	0	10	51	11
7-8 Hour 8	Prot	10	27	10	27	LtPerm	0	10	0	10	53	14
8-9 Hour 9	Prot	10	25	10	25	LtPerm	0	10	0	10	51	12
Mid-Day												
9-10 Hour 10	Prot	10	25	10	25	LtPerm	0	10	0	10	51	11
10-11 Hour 11	Prot	10	25	10	25	LtPerm	0	10	0	10	51	10
11-12 Hour 12	Prot	10	25	10	25	LtPerm	0	10	0	10	51	11
12-1 Hour 13	Prot	10	25	10	25	LtPerm	0	10	0	10	51	12
1-2 Hour 14	Prot	10	25	10	25	LtPerm	0	10	0	10	51	12
2-3 Hour 15	Prot	10	25	10	25	LtPerm	0	10	0	10	51	12
3-4 Hour 16	Prot	10	25	10	25	LtPerm	0	10	0	10	51	12
PM												
4-5 Hour 17	Prot	10	26	10	26	LtPerm	0	10	0	10	52	13
5-6 Hour 18	Prot	10	27	10	27	LtPerm	0	10	0	10	53	14
6-7 Hour 19	Prot	10	25	10	25	LtPerm	0	10	0	10	51	12
Off-Peak												
7-8 Hour 20	Prot	10	25	10	25	LtPerm	0	10	0	10	51	11
8-9 Hour 21	Prot	10	25	10	25	LtPerm	0	10	0	10	51	10
9-10 Hour 22	Prot	10	25	10	25	LtPerm	0	10	0	10	51	10
10-11 Hour 23	Prot	10	25	10	25	LtPerm	0	10	0	10	51	9
11-12 Hour 24	Prot	10	25	10	25	LtPerm	0	10	0	10	51	9
12-1 Hour 1	Prot	10	25	10	25	LtPerm	0	10	0	10	51	9
1-2 Hour 2	Prot	10	25	10	25	LtPerm	0	10	0	10	51	9
2-3 Hour 3	Prot	10	25	10	25	LtPerm	0	10	0	10	51	9
3-4 Hour 4	Prot	10	25	10	25	LtPerm	0	10	0	10	51	9
4-5 Hour 5	Prot	10	25	10	25	LtPerm	0	10	0	10	51	9

Check Hourly /Annual Safety Output

Hourly Summary of Annual Data									HISTORIC SULLY	&		TURLEY HA
	Estimated Delay/Year		Annual Vehicle-Only Events									
	Major Road Appr. 1&3	Minor Road Appr. 2&4	Forecast Accident Events						Forecast Injury Events			
HOUR	Hours/Year	Hours/Year	Total/Yr	WITH-IN	Rear-End	Sideswipe	Fixed Obj/Sir	HOUR	TOTAL/Yr	Critical/5-Yrs	HOUR
1	41	42	0.00	0.00	0.00	0.00	0.00	1	0.00	0.00	1
2	23	24	0.00	0.00	0.00	0.00	0.00	2	0.00	0.00	2
3	15	15	0.00	0.00	0.00	0.00	0.00	3	0.00	0.00	3
4	19	19	0.00	0.00	0.00	0.00	0.00	4	0.00	0.00	4
5	34	34	0.00	0.00	0.00	0.00	0.00	5	0.00	0.00	5
6	137	140	0.02	0.01	0.00	0.00	0.02	6	0.00	0.00	6
7	387	396	0.10	0.05	0.01	0.00	0.04	7	0.02	0.00	7
8	987	1,010	0.26	0.14	0.06	0.00	0.06	8	0.08	0.00	8
9	787	805	0.15	0.08	0.02	0.00	0.05	9	0.04	0.00	9
10	533	545	0.09	0.04	0.01	0.00	0.03	10	0.02	0.00	10
11	389	399	0.05	0.03	0.00	0.00	0.03	11	0.01	0.00	11
12	456	466	0.06	0.03	0.00	0.00	0.03	12	0.01	0.00	12
13	693	709	0.11	0.06	0.01	0.00	0.04	13	0.03	0.00	13
14	688	705	0.13	0.07	0.01	0.00	0.05	14	0.03	0.00	14
15	615	630	0.13	0.08	0.01	0.00	0.05	15	0.03	0.00	15
16	800	819	0.19	0.12	0.02	0.00	0.06	16	0.05	0.00	16
17	1,106	1,132	0.28	0.17	0.04	0.00	0.07	17	0.08	0.00	17
18	2,083	2,132	0.41	0.25	0.08	0.00	0.08	18	0.13	0.01	18
19	926	947	0.23	0.14	0.03	0.00	0.06	19	0.07	0.00	19
20	435	446	0.10	0.05	0.01	0.00	0.04	20	0.02	0.00	20
21	266	272	0.05	0.02	0.00	0.00	0.02	21	0.01	0.00	21
22	216	221	0.03	0.01	0.00	0.00	0.02	22	0.01	0.00	22
23	139	142	0.02	0.01	0.00	0.00	0.01	23	0.00	0.00	23
24	77	79	0.01	0.00	0.00	0.00	0.01	24	0.00	0.00	24
TOTAL/Yr	11,851	12,130	2.4	1.37	0.32	0.00	0.76		0.65	0.03	
	Delay/Year	Delay/Year	Accidents/Yr	WITH-IN	Rear-End	Sideswipe	Fixed Obj/Sir		Injury Acc./Yr	Critical/5-Yrs	
									Fatal/5-Yrs		
										Note: The rate-b	

Alternative ADT-Based (Macro) Accidents/Yr Estimate

MDOT-Round Acc/Yr =	2.5	Large Urban Std.Dev.=	
		Small Urban Std.Dev.=	

Alternative ADT-Based Injury Accidents/Yr Estimate

MDOT-Roundabout Inj-Acc./Yr =	0.6	Large Urban Std.Dev.=	
UK Roundabout Inj-Acc./Yr=	0.6	Small Urban Std.Dev.=	

TRAF-Safe Safety Levels of Service

Safety Los 'A' <	0.43	Traf-Safe Safety LOS Criteria	
Safety Los 'B' <	0.87	0.65	Traf-Safe Injury Acc.+Peds/Y
Safety Los 'C' <	1.30		
Safety Los 'D' <	1.74	PLANNING LIMIT OF ACCEPTABLE RISK	
Safety Los 'E' <	2.17	DESIGN LIMIT OF ACCEPTABLE RISK	
Safety Los 'F' >	2.17	POTENTIALLY HAZARDOUS DESIGN	

Compare to FHWA & British Macro-Safety Models

Macroscopic ADT-based Regression Models by Others for Comparison

7.72	= Accidents/Yr Estimate
3.18	= Injury Accidents/Yr Estimate

SCROLL DOWN TO SEE:

1. ALL-WAY STOP ADT MODEL (2000 HCM)
2. ROUNDABOUT ADT MODEL (2000 HCM)
3. ROUNDABOUT SUMMARY (UK MODEL)
4. FHWA ADT M FALSE
   - 3-LEG TWSC RURAL
   - 4-LEG TWSC RURAL
   - 3-LEG TWSC URBAN
   - 4-LEG TWSC URBAN
   - 4-LEG AWSC URBAN
   - 4-LEG SIGNAL URBAN
5. AASHTO LEFT BAY WARRANT MODEL
6. FROM FHWA ROUNDABOUTS GUIDE (2000)
   - UK FALSE
   - AUS. ROUNABOUT ADT MODEL (Acciden
7. NCHRP 17-16 ADT ACCIDENT MODEL (2003)
8. FHWA INJURY ACCIDENT MODELS:
   - 4-LEG SIGNAL URBAN
   - 4-LEG TWSC URBAN
   - 4-LEG TWSC RURAL
9. VDOT ACCIDENT & INJURY ACCIDENT MODELS:
   - 4-LEG SIGNAL URBAN
   - 3-LEG SIGNAL URBAN
   - 4-LEG ST FALSE
   - 3-LEG STOP URBAN

FROM "Statistical Models of At-Grade Intersection Accidents" - Addendum, USDOT Publication No. FHWA-RD-99-094, March, 2000

RURAL 3-LEG STOP CONTROL MACRO (ADT-BASED) MODEL Accidents & Injury Accidents/yr

FHWA Accident Model - 4/2000 (Light Blue cells may be individually input)

	Major	Minor	MajorLeft Bay?		AccessC.	Fun.Class		Rt.Sh.Width?	Terrain	
bo	b1	b2	b3	b4	b5	b6	b7	b8	b9	b10
-9.18	0.83	0.38	0.21	0.12	0.23	0.15	0.21	-0.02	-0.05	0.10
ACCIDENT	ANSWER		0.00	1.00	1.00	1.00	0.00	5.70	1.00	0.00
8.398	25.195	Inputs =	No paint	Curb	none	Minor	no	5.70	flat	
Acc/Yr	Acc/3Yr.		Paint/None	Curb/None	partial/none?	Prin/Minor Art.	Collector?	0-10	Flat/Not?	Mountainous/Not
32.00	8.01	ADT INPUTS/100				>15,000Entering				
MajorADT^	MinorADT^									

FHWA Injury+Fatality Accident Model - 4/2000

	Major	Minor	Rt.Sh.Width?	Lighting	MajorLeft Bay?		Fun.Class		CrossroadFree
bo	b1	b2	b3	b4	b5	b6	b7	b8	b9
-9.14	0.78	0.38	-0.03	0.17	0.18	0.06	0.16	0.19	-0.22
INJURY ACC.	ANSWER		5.70	0.00	0.00	1.00	1.00	0.00	1.00
3.157	9.471	Inputs =	5.70	no	No paint	Curb	Minor	no	No
Inj.Acc/Yr	I.Acc/3Yr.		0-10	Lighted/Not?	Paint/None	Curb/None	Prin/Minor Art.	Collector?	No/Yes?

(CHECK: 8.0 Major and 3.0 Minor = 1.458 and 0.585 respectively)

RURAL 4-LEG STOP CONTROL MACRO MODEL

FHWA Accident Model - 4/2000

	Major	Minor	#Lanes Major(2-	Des.Speed	AccessC.	Fun.Class		Lighting	Terrain		s?(Free=YIELD w
bo	b1	b2	b3	b4	b5	b6	b7	b8	b9	b9	b9
-10.03	0.53	0.76	0.32	0.01	0.20	0.18	0.17	0.12	0.05	0.05	0.05
ACCIDENT	ANSWER		0.00	50.00	1.00	1.00	0.00	1.00	1.00	0.00	1.00
13.202	39.606	Inputs =	no	50.00	none	Minor	no	no	flat		No
Acc/Yr	Acc/3Yr.		Maj.Lanes<=3	Design Spd.?	partial/none?	Princ./Minor?	Collector?	lighted/Not?	Flat/Rolling?	Mount./Not?	No/Yes?
32.00	8.01	= Inputs									
MajorADT^	MinorADT^										

FHWA Injury+Fatality Accident Model - 4/2000

	Major	Minor	anes Major(2-w	Des.Speed	Fun.Class		Lighting	Terrain	
bo	b1	b2	b3	b4	b5	b6	b7	b8	b9
-10.29	0.55	0.68	0.39	0.01	0.26	0.17	0.22	0.18	-0.23
INJURY ACC.	ANSWER		0.00	50.00	1.00	0.00	0.00	1.00	0.00
5.276	15.827	Inputs =	no	50.00	Minor	no	no	flat	
Inj.Acc/Yr	I.Acc/3Yr.		Maj.Lanes<=3	Design Spd.?	Princ./Minor?	Collector?	lighted/Not?	Flat/Rolling?	Mount./Not?

FALSE

(CHECK: 8.0 Major and 3.0 Minor = 2.790 and 1.471 respectively)

Recognize that : Regression Accident Model Accuracy < 35 % Accurate

DELAY RESULTS ??

	HCS-based Delay	Conflict Software Delay
TWSC		
Am	8.1	6.3
Pm	14.9	6.7
AWSC		
Am/Pm LOS	B	F
Signal		
Am	8.9	11.9
Pm	8.8	15.0
Roundabout		
Am	9.5	20.6 [1]
Pm	10.3	33.4 [1]

1. Very conservative lower bound critical gap

Within the 30% error margin

when comparing HCS results to actual field delay

SAFETY RESULTS ??

Accidents - Injuries - Lifetime Risk

	TWSC	AWSC	Signal	Roundabout
Accidents	0.5	1.5	1 .4	2.4
Injury Acc.	0.12	0.15	0.42	0.65
Safety LOS	B	B	A	B
Performance Index (Safety+Delay Value)	58	741	94	133

Conclusions ?

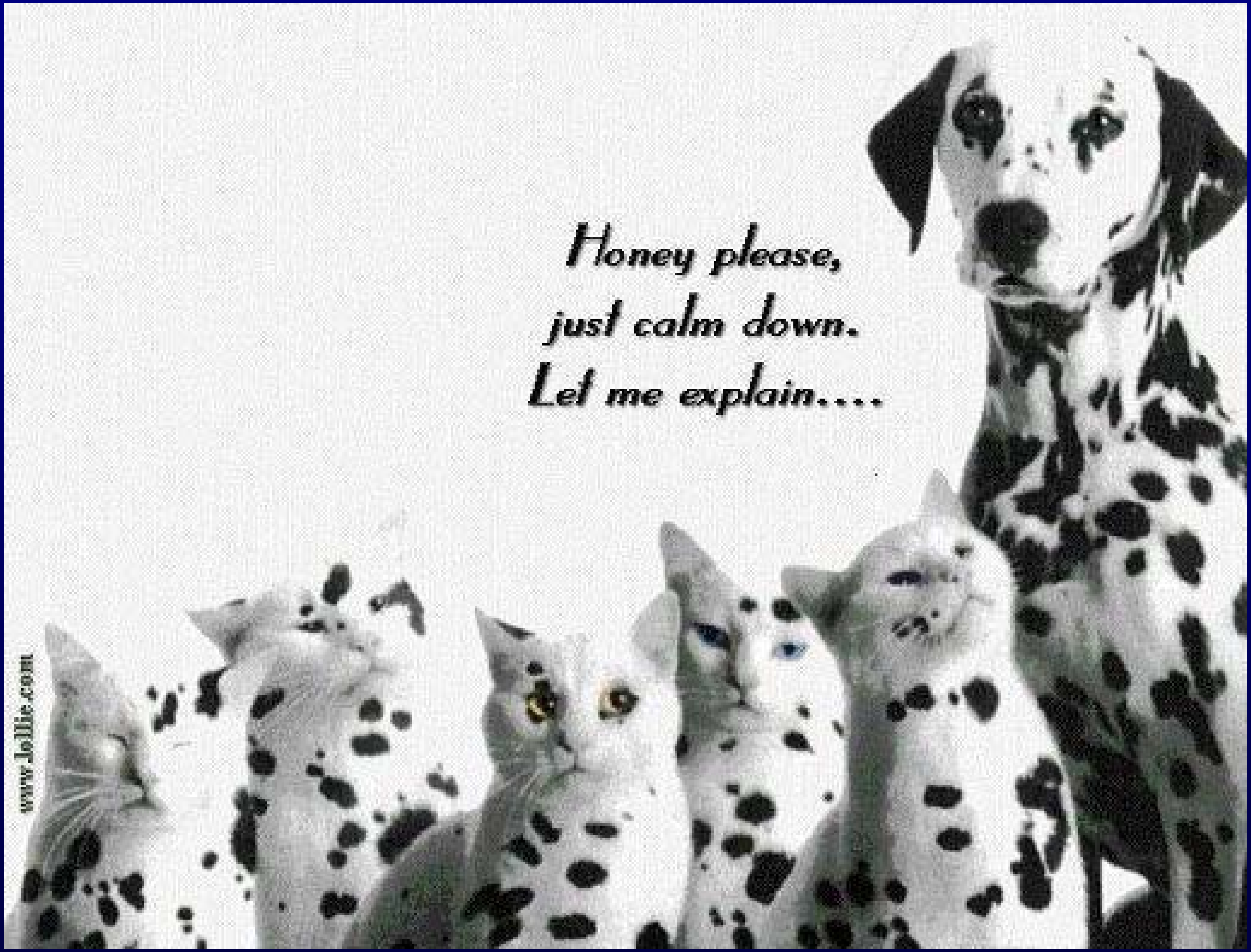
1. AWSC - Unacceptable delay = LOS "F"
2. Signal may not warrant (15,000 ADT) - annual cost
3. TWSC and Roundabout Safety LOS = B = OK
4. Thus developer may select TWSC or Roundabout

(Both are acceptable and only have slight differences)

If Had Walk/Bike Mode Injury Accident Estimation can be included

WALK/BIKE MODULE		COMMENTS	9/3/04 12:03 PM
		MAJOR ROADWAY	MINOR ROADWAY
Walk/Bike Mode Total Injury Events/5-Yrs =		0.00	
Walk/Bike Mode Critical Injury Events/5-Yrs =		0.00	
APPROACH 1 & 2		Major # 1	Minor # 2
Total WALK/BIKE Distance on this Approach (ft) =		72	48
Total WALK/BIKE Mode per Day (this approach) =		0	0
Percent Young Crossing (age 2-14)/Day =		0	0
Percent Typical Crossing (age 15-55)/ Day =		95	95
Percent Elder Crossing (ages > 55)/ Day =		5	5
Percent Crossing Handicap Peds/ Day =		0	0
Effective Total Crossings Walk+Bike/Day =		0	0
AADT This Approach =		30,790	9,218
WALK/BIKE Injury Events/5-Yrs this approach =		0.000	0.000
Percent Critical Injuries =		43%	24%
Estimated Critical Events/5-Yrs =		0.000	0.000
APPROACH 3 & 4		Major # 3	Minor # 4
Total WALK/BIKE Distance on this Approach (ft) =		72	48
Total WALK/BIKE Mode per Day (this approach) =		0	0
Percent Young Crossing (age 2-14)/Day =		0	0
Percent Typical Crossing (age 15-55)/ Day =		95	95
Percent Elder Crossing (ages > 55)/ Day =		5	5
Percent Crossing Handicap Peds/ Day =		0	0
Effective Total Crossings Walk+Bike/Day =		0	0
AADT This Approach =		30,790	9,218
WALK/BIKE Injury Events/5-Yrs this approach =		0.000	0.000
Percent Critical Injuries =		43%	24%
Estimated Critical Events/5-Yrs =		0.000	0.000

But let's remember….it's just software



Only <u>qualified engineering judgment</u> can define what's safe & what's not…..but software can help defend your decision and explain why.