APPENDIX U
MEDIAN WIDTH & SAFETY

Rural Freeways
Relationship of Median Width and Safety
Summary of Peer-Reviewed Findings
Revised, September 2009

Summary

This Tier 2 EIS uses two sets of design criteria for I-69 alternatives. These criteria (designated as the "initial" and "low cost" criteria) are applied to obtain a range of possible construction costs. One significant difference between the two sets of design criteria is that the initial criteria specify an 84-foot median for rural sections of I-69, while the low cost criteria specify a 60-foot median for rural sections.

The Federal Highway Administration (FHWA) has requested an evaluation of the safety implications, if any, of using 60-foot medians instead of 84-foot medians for rural sections of I-69. This technical memo and analysis provides this evaluation. This memo originally was completed in October of 2008 for release with the Draft Environmental Impact Statements of Sections 2 and 3 of the I-69 project. It was updated in September of 2009 to incorporate additional recently-published research.

The key findings are as follows:

- ***There is little, if any, safety benefit for increasing median width beyond 60 feet for rural freeways.*** Two studies (Knuitman et al. and Lu et al.) identify ***no*** incremental safety benefit for median widths beyond 60 feet. Two other studies (Hadi et al. and Donnell et al.) suggest there may be a ***small*** safety benefit.
- ***The magnitude of the potential cost savings of using 60-foot medians is much larger than any potential user safety benefit.*** One study (Donnell, et al.) showed that widening medians beyond 60 feet provides a small reduction in crashes. This study included a detailed tabulation of median widths and crash rates for Interstate highways. These results were applied to Section 3 of I-69 to provide an "order of magnitude" estimate of potential safety benefits of an 84-foot median. Application of these results indicates that an 84-foot median would avoid one crossover crash every 16 – 17 months in Section 3, with an annual safety benefit of about $610,000. By comparison, the project cost savings attributable to using a 60-foot median instead of an 84-foot median in Section 3 is $12 to $18 million.[1] This should be regarded as a ***high end*** estimate of the potential safety benefit; two of the studies analyzed here (Knuitman and Lu) suggest a negligible safety benefit.
- ***A number of geometric elements, cross-sectional design elements, and driver behaviors affect cross-median crash rates on rural freeways.*** These include horizontal curvature, pavement friction, shoulder design, median surface, alignment consistency, median cross-slopes, pavement cross-slopes and superelevation, operating speed, and consideration of weather factors.

[1] Also, any project cost savings will be realized in the next 5 – 7 years. The traffic forecasts underlying this user safety benefit assume that I-69 is completed from Evansville to Indianapolis. Until that occurs, the estimated user benefits would be less than stated here.

Background

The engineering guidance provided to Environmental and Engineering Consultants (EEACs) at the start of the I-69, Evansville-to-Indianapolis Tier 2 studies included use of an 84-foot median in typical rural cross-section for the I-69 mainline. As the studies have progressed, several engineering refinements are being considered. One of these is use of a 60-foot median for rural sections. This would allow for a narrower typical section, which would reduce right-of-way costs, construction costs, and environmental impacts.

This technical memo is provided to assess what safety impacts could be anticipated if a narrower median is used. Specifically, what (if any) effects can be anticipated on crash rates if a 60-foot median is provided, rather than an 84-foot median?

Literature Review

The following sources were identified which provide research results regarding the relationship between median width and crash rates.

1. ***Association of Median Width and Highway Accident Rates. Knuitman, Council and Reinfurt. 1993. Published in TRR 1401.***

2. ***Estimating Safety Effects of Cross-Section Design for Various Highway Types Using Negative Binomial Regression. Hadi, Aruldhas, Chow and Wattleworth. 1995. Published in TRR 1500.***

3. ***Crash Reduction Factors for Improvement Activities in Indiana. Tarko, Sinha, et al. 2000. Joint Transportation Research Program, Project C-36-78A.***

4. ***Cross-Median Collisions on Pennsylvania Interstates and Expressways. Donnell et al. 2002. Published in TRR 1784.***

5. ***Roadway Safety Design Synthesis. Bonneson, Zimmerman and Fitzpatrick. 2005. Published by Texas Transportation Institute.***

6. ***Analysis of the Magnitude and Predictability of Median Crossover Crashes Using Logistic Regression. Lu, Noyce and McKendry. Presented at January, 2006 TRB Annual Meeting.***

7. ***Desktop Reference for Crash Reduction Factors. FHWA Publication FHWA-SA-07-015. 2007.***

8. ***Cross Median Crashes: Identification and Countermeasures. Davis, University of Minnesota. Published by Minnesota Department of Transportation. 2008.***

9. ***Guidance for Implementation of the AASHTO Strategic Highway Safety Plan. Volume 20: A Guide for Reducing Head-On Crashes on Freeways. NCHRP Report 500. 2008.***

10. ***Impact of Shoulder Width and Median Width on Safety. Stamatiadis, Pigman, Sacksteder, Ruff and Lord. NCHRP Report 633. 2009.***

Source 7 provides two equations (p. 73) which give the relationship between crashes and median width on all rural highways, and on all freeways. It takes these equations directly from Source 5. Source 5, in turn, derives its equations from sources 1 and 2. After some remarks about sources 5, 7, and 9, this analysis of the relationship between median widths and crashes will review the findings in sources 1, 2, 3, 4, 6, 8 and 10.

Roadway Safety Design Synthesis (Source 5) is the final report (published in 2005) of a project performed in cooperation with the Federal Highway Administration and the Texas Transportation Institute (TTI). TTI is one of the nation's foremost university-affiliated transportation research centers. The report is a compilation of the state of knowledge about the relationship of key design components to street and highway safety. Its abstract states that "It is envisioned to be a reference document which will be useful to engineers and researchers who desire detailed safety information on various highway geometric design elements."

Desktop Reference for Crash Reduction Factors (Source 7) was published in 2007 to document the state of knowledge regarding Crash Reduction Factors (CRFs). This document's abstract states regarding its contents, "The estimates of crash reduction are known as Crash Reduction Factors (CRFs), and represent the information available to date."

NCHRP Report 500 (Source 9) is the 20th in a series of reports providing strategies to implement AASHTO's Strategic Highway Safety Plan. This report addresses median widening of existing freeways. It recognizes that widening medians on existing freeways is an expensive, multi-year process. It cites only one additional peer-reviewed research paper not already discussed in this technical memo. This additional paper was published by Garner and Deen in Highway Research Record 432 in 1973. This HRR report analyzed crash data from Kentucky, and found that crash rates leveled off for median widths of 40 feet and greater.

Documents 5 and 7 are written or sponsored by FHWA as state-of-the-practice summaries of the best available information regarding the relationship between highway geometrics and crashes. As noted above, the only two original research which both reports draw upon are Source 1 (Knuitman, et al) and Source 2 (Hadi et al).

Knuitman, et al (1993)

This analysis obtained roadway inventory, accident data, and traffic volume data for five states (Illinois, Utah, Michigan, Minnesota and Maine). After extensive checking and preliminary investigation, it determined that two of the states (Utah and Illinois) provided data which were sufficiently complete and reliable for this analysis. In order to isolate the effect of median width, other variables were used in the regression analysis. These included posted speed limit, right shoulder width, daily traffic, and section length.[2]

For both the Utah and Illinois data, the median width was analyzed in category ranges. The Utah data analyzed all medians between 55 and 84 feet within a single category. Accordingly, the analysis of the Utah data is not applicable to the comparison of 60- vs. 84-foot medians. The Illinois data were grouped into three categories, as follows:

- 55 – 64 feet (mean value 63.8 feet)
- 65 – 84 feet (mean value 71.9 feet)
- 85 – 110 feet (mean value 88.9 feet)

The ranges in which the Illinois data were classified make it applicable to this analysis.

The analysis of Illinois data considered all accidents over a three-year period (1987 – 1989). It studied crash data for a total of 860 highway segments[3] with medians between 55 and 110 feet. There were:

- 450 highway segments with medians of 55 – 64 feet,
- 239 highway segments with medians of 65 – 84 feet, and
- 171 highway segments with medians of 85 – 110 feet.

The analysis estimated the relative change in total accident rates as a function of median width (where a median width of 0 is considered the base case). The analysis found that the ability of wider medians to reduce crashes "levels off" in the 60 – 80 foot range. The report states on p. 76, "The decreasing trend seems to become level at median widths of approximately 60 to 80 ft (18.3 to 24.4 m), particularly for Illinois." This finding is reiterated in Hadi, et al., citing this study.

Figure 1 from the TRR 1401 printed study is provided below, showing the relationship between median width and relative effect on crash rates for the Illinois data. This equation which generated this graph was derived using negative binomial log-linear regression (the binomial

[2] The data set included roads other than fully access-controlled freeways. Accordingly, the data set also included access control and functional classification. For rural freeways (our focus) neither of these factors varies.
[3] While the published report in TRR 1401 does not indicate how many of these highway segments are in rural areas, it may be assumed that the significant majority of them are. Table 1 of the report states that the study sample includes 846 rural interstate segments; it is highly unlikely that more than a few of these 846 segments would have medians less than 55 feet in width.

relationship is similar to a Poisson[4] distribution, but it allows the mean to differ from the variance). Log-linear regression also assumes that the effects of the independent variables are multiplicative rather than additive (as in linear regression).

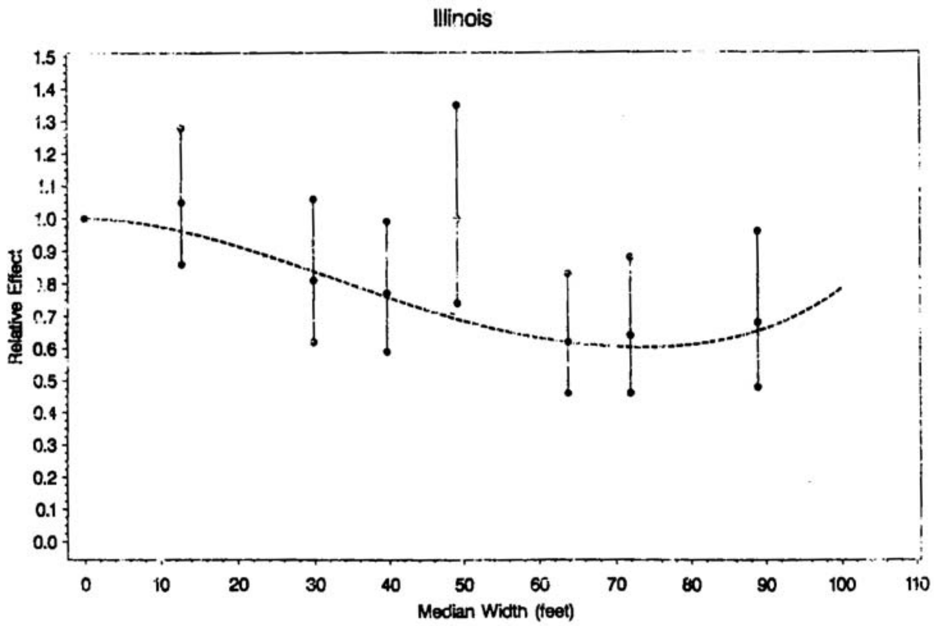

FIGURE 1 Estimated relative effects of median width on the total accident rate when median width is represented both as a categorical variable and as a continuous variable, adjusting for functional class, posted speed limit, right shoulder width, access control (Illinois only), curvature (Utah only), log (ADT) and log (section length). Note: 1 ft = 0.305 m.

Reproduced from TRR 1401, p. 75

The log-linear regression actually shows a slight increase crash rates as median widths increase beyond 60 feet. This difference is slight, but illustrates the conclusion that (based upon these data) the relative ability of medians to reduce crash rates levels off after medians reach about 60 feet in width.

Conclusion: A study of three years of accident data in Illinois for 860 highway segments, nearly all of which were in rural areas, concluded that there is a “leveling off” of the ability of median widening to reduce crashes once medians are 60 feet in width. As it would apply to I-69, it suggests that there is no negative safety impact for using a 60-foot median, as compared to an 84-foot median.

[4] P. 72 of TRR 1401 states, “The classical distribution for accident counts is the Poisson distribution for which the variance is equal to the mean. However, variances in excess of the mean are often observed (cites Breslow in *Applied Statistics*, Vol. 22, 1984, pp. 38-44), partly because not all relevant variables are included in the model.”

Hadi, et al (1995)

This analysis used four years of crash data from Florida to analyze the relationship between cross-sectional design elements and crash rates. This analysis was performed for six different categories of urban roads and three different categories of rural roads. One of the rural road categories was rural freeways. The published documentation does not provide sample sizes for the number of road segments analyzed; it simply states that "The largest possible number of roadway segments from the state of Florida roadway system were (sic) used in this study." (p. 170)

Equations were estimated to forecast crash rates for all crashes, as well as injury crashes and fatal crashes. Approximately 19 independent variables were considered in the analysis; no more than eight were found to be significant for any one equation.

The equations to forecast crash rates for rural freeways use the square root of median width as an independent variable to predict all crashes, as well as injury crashes. Median width was not found to be a significant variable for prediction of fatal crashes.

The equations forecast a moderate decrease in the number of crashes for use of an 84-foot median versus a 60-foot median. For a range of section lengths (0.5 to 2.0 miles) and AADT (10,000 to 30,000), an 84-foot median is forecasted to reduce all crashes by 6.4 – 6.8%, and is forecasted to reduce injury crashes by 6.1% - 6.4%, as compared to a 60-foot median. As noted above, median width was not found to be a significant predictor of fatal crash rates.

There is one caveat. This report does not disclose actual crash rates by ranges of median widths, as was provided in Knuitman. This equation represents the results of "fitting a curve" using negative binomial regression. The actual data for medians in the 60 – 84 foot range will differ somewhat from predictions of this equation.

The report also noted that median widths had a smaller effect on crash rates for rural freeways than for any other functional classification. P. 176 of the report states, "The safety benefit of increasing median width seems to be the highest in four-lane urban freeways and six-lane urban highways followed by six-lane urban freeways and four-lane urban highways followed by four-lane rural highways and rural freeways." The report (p. 170) also cites Knuitman's work to state, "Knuitman et al. studied the effect of median width on crash rate using a negative binomial regression model. For a median without a barrier, it was found that crash rates declined rapidly when median width exceeded about 7.6 m (25 ft). The decreasing trend seemed to become level at median widths of approximately 18.9 to 24.4 m (60 to 80 ft)."

Conclusion. A four-year study of crash data in Florida was used to provide equations to predict crash rates (for various types of crashes) for all classes of roads as a function of cross-section design characteristics. For rural freeways, the equations predicted that an 84-foot median would provide a 6.1% to 6.8% reduction in crash rates, as compared to a 60-foot median. However, the actual data used to estimate these equations were not provided or summarized.

Tarko, et al (2000)

This study was a Joint Transportation Research Project (JTRP) to determine “crash reduction factors” (CRFs) for various improvement types, as part of development of a Safety Management System for INDOT under ISTEA. It used log-linear negative binomial regression to determine equations which predicted the number of crashes as functions of the roadway physical characteristics and AADT. A crash reduction factor for a specific type of improvement was then specified using the slope parameter associated with the variable in question.

A crash database for the years 1991 through 1995 was obtained from the Indiana State Police. INDOT’s Road Inventory Database, along with additional county-level data, was used to specify roadway characteristics. The log-linear regression was performed in a stepwise manner using approximately 28 independent variables, one of which was median width. The basic model was developed with only AADT and section length as the independent variables. Then each independent variable was added in sequence to test its significance.

The study documentation did not specifically describe the sample of rural freeways used in this analysis. However, the documentation indicates that its results are not applicable in our analysis.

Table 2.3 (p. 23) of this report provides a summary of the coefficients of significant variables for rural, multilane highways analyzed in this study. This table states that only 47 rural multi-lane roadway segments were analyzed. This includes freeways, expressways, and multilane roads with no access controls.[5] Given that these 47 segments studied had three possible types of access control, the number of segments corresponding to rural freeways is small.[6]

Given a small sample of rural freeways, there are an inadequate number of samples for assessing the relative effects of 60- vs. 84-foot medians for rural freeways.[7] Knuitman, et al analyzed crash data from 860 rural highway sections with median widths of 55 feet and greater; the number of samples of rural highways with medians 55 feet or wider in this study almost certainly was no more than 1 – 2% of Knuitman’s total.

[5] One of the other significant predictive variables for rural multilane roads was type of access control. This variable could have three values, corresponding to no access control, partial access control, and full access control.
[6] Version 4 of the Indiana Statewide Transportation Demand Model (ISTDM) shows that of the 1,759 center-line miles of rural divided roads in Indiana, 854 miles (49%) are fully access-controlled freeways. Source: Dean Munn to Michael Grovak e-mail, May 23, 2008.
[7] Also, the study’s purpose was to identify CRFs for improvements which INDOT might undertake. Widening medians which already are 50 – 60 feet wide would be a low priority project. Given the study’s purposes, there would be little reason to include highway segments with medians significantly wider than 60 feet in the dataset.

Also, the crash reduction factors computed for median widths are functions only of the ***change*** in median width – the actual median widths before or after the improvement are not considered. For example (Table 2.7a, p. 34), the crash reduction factor for a 20-foot median widening is 41% for injury accidents. This factor predicts a 41% decrease in injury accidents for widening a 10 foot median to 30 feet, widening a 20 foot median to 40 feet, or widening a 60-foot median to 80 feet.

Such results are counterintuitive, as well as inconsistent with other research reviewed in this memorandum. However, if we understand that this factor should be applied only to medians much narrower than those we are considering in this evaluation, then there is no inconsistency. See the quote given above from Hadi's citation of Knuitman's work, which states that there are significant safety improvements for widening medians at or above 25 feet in width. However, the safety benefit of median widening "levels off" in the 60 – 80 foot range.

Conclusion. This JTRP study has a sample size for rural highways which is a small fraction of Knuitman's study. Its crash reduction factors are appropriate for much narrower medians than are being evaluated for the I-69 project. Its results are not applicable for this study.

Donnell et al (2002)

This paper documents research to evaluate the policies of the Pennsylvania Department of Transportation (PENNDOT) to provide median barriers where medians are under 10 m (approx. 33 feet) wide and have ADT of at least 20,000. The study evaluated whether roads with wider medians and/or lower traffic levels also should have median barriers.

This study analyzed Cross Median Crashes (CMCs) from PENNDOT's Crash Reporting System (CRS) between 1994 and 1998. It identified 138 such crashes which occurred on Interstate highways during this five year period (Table 2). Table 2 also provides a breakdown of CMCs by type. For all CMCs, 17.4% were fatal crashes, 67.4% were injury crashes, and 15.2% were property-damage only crashes.

Table 3 in this study also provided CMC crash rates per 100 million VMT cross-classified by median width. Unlike some of the other studies analyzed in this paper, it did show a small decrease in the CMC crash rates in going from a 60-foot median to wider medians. The data in Tables 2 and 3 may be used to provide an "order of magnitude" assessment of the possible safety benefits of wider medians.

To specify the CMC crash rate for roads with 60-foot medians, the data in Table 3 are used to compute a crash rate of 0.67 crashes/100 million VMT. This is calculated as the average of CMC crash rates for Interstate highways with 51 – 60 foot medians (0.89/100 million VMT) and 61 – 70 foot medians (0.44/100 million VMT). Table 3 reports no crashes for Interstate highways with 81 – 90 foot medians; as a proxy, the crash rate for highways with 91 – 100 foot medians (0.27/100 million VMT) is used. The difference of these two crash rates (0.40/100 million VMT) is used to estimate CMC crashes avoided in using an 84-foot median in place of a 60-foot median.

INDOT's NET_BC post processor assigns dollar values to each crash type (fatal, injury and PDO) avoided.[8] These costs (in Year 2007 dollars) are $4.51 million for fatal crashes, $98,000 for injury crashes, and $5,200 for property damage only crashes. Applying these costs to the percentages of CMC crashes by type given above gives a weighted average of $850,000 for each CMC avoided.

As an "order of magnitude" example, these crash rates and safety benefits are applied to traffic forecasts and construction cost estimates in I-69 Section 3. The forecast year (2030) ADT in Section 3 (25.7 miles for the preferred alternative) is about 21,000. Annual forecast year (2030) VMT is calculated as 178,000,000 in Section 3 (21,000*330*25.7). Using the Pennsylvania data, the difference in crash rates between facilities with 60- and 84-foot medians is about 0.40/100 million VMT. Applying this crash rate reduction shows 1 CMC avoided every 16 – 17 months.

It must be noted that these traffic forecasts assume that I-69 is completed between Evansville and Indianapolis. This full level of user benefit would not be realized until many years in the future. By comparison, any savings in construction cost will be realized in the next 5 – 7 years. Section 3 of I-69 is fully funded by Major Moves proceeds, and the INDOT Long Range Plan calls for construction in Section 3 to commence by 2015.

Using an estimated savings of $850,000 per CMC avoided, the annual safety benefit would be approximately $610,000. By comparison, the project cost savings for the low-cost design criteria (compared to the initial design criteria) is $80 - $90 million; about 15 – 20% of this cost savings ($12 to $18 million) is directly attributable to the reduced median width.[9] Using the Pennsylvania data, the annual user benefits for the wider medians are about 3• – 5% of the project cost savings. ***It must be cautioned that this is only an "order of magnitude exercise", and does not represent a structured benefit-cost or net project value calculation.***[10] Rather, it illustrates by applying the Pennsylvania data to the I-69 project, that the added safety benefits are small compared with the project cost savings.

The analysis produced two equations to forecast the number of cross-median crashes per year for a given highway segment as a function of ADT and median width. However, these equations

[8] NET_BC is a post-processor to the Indiana Statewide Travel Demand Model (ISTDM). It compares traffic model forecasts to estimate user benefits (travel time, vehicle operating, and safety) of transportation improvements. These costs by crash type are those currently used in NET_BC.
[9] Reducing the median width provides cost savings due to reduced earthwork (cut/fill), smaller structures for grade separations, reduced culvert length and reduced ROW clearing costs. These cost savings are documented in an e-mail from Michael Grovak to Jim Gulick, dated September 25, 2008.
[10] A formal analysis would need to quantify the timing of benefits and costs, and discount each appropriately. As stated in the previous paragraph, any project cost savings are realized much sooner than the ***full*** user benefits stated here.

have little explanatory power. Their r-squared (representing the proportion of the variation in CMC crash rates which they explain) are 0.07 and 0.13 (p. 98). In other words, they fail to explain 87 – 93% of the variation in crash rates. Quoting from p. 98 of the paper, "Both models provide a relatively poor fit to the data. As a result, these models, although statistically significant, have little predictive power and thus do not allow a user to predict crashes with great certainty based on traffic volume and median width."

As part of this study, a Delphi panel of state DOT and other transportation experts was convened. They identified a number of geometric and cross-sectional elements which contribute to cross-median collisions. The 10 most significant were:

- Horizontal curvature
- Operating Speed
- Median Cross Slopes
- Driver Behavior
- Pavement Friction
- Pavement Cross Slope & Superelevation
- Weather
- Shoulder Design
- Median Surface
- Alignment Consistency

Conclusion. This report, unlike some of the others cited, did suggest there is a small difference in crash rates between Interstate highways with 60- and 84-foot medians. Its results were applied in an "order of magnitude" assessment of the relative costs and safety benefits for a portion of I-69 (Section 3). This assessment shows that the added annual safety benefits of the 84-foot median (when I-69 is ***completed*** between Evansville and Indianapolis) would be about 3• – 5 % of the project cost savings. Construction of Section 3 is funded and is scheduled to begin by 2015, so that project cost savings will be realized in the near future. By contrast, the safety benefits calculated here assume traffic levels realized when ***all*** of I-69 is completed from Evansville to Indianapolis, which will not occur until many years after 2015.

This estimate of user safety benefit is a ***high end*** estimate. Other studies analyzed in this paper (Knuitman and Lu) suggest that there is no meaningful difference in crash rates for widening medians beyond 60 feet.

The study also found that median width (along with traffic) has "little predictive power" in forecasting median crossover crash rates. The expert panel convened for this study identified a number of other geometric and cross-sectional elements which contribute to cross-median collisions.

Lu et al (2006)

This study analyzed the relationship between a variety of factors (including median width) and a specific kind of crash, median crossover crashes. This kind of crash is defined as "an accident in which a vehicle traverses the median area and penetrates into the opposing travel lane. Crashes vary from vehicles coming to rest in the opposing lane, to vehicles passing through the opposing lane without hitting an opposing vehicle, to head-on or sideswipe impacts with opposing vehicles." (p. 1)

The paper analyzed 15,194 crashes on Wisconsin's divided freeways and expressways between 2001 and 2003. It identified 631 of these as median crossover crashes (MCCs).

The following is quoted from p. 8 of the paper. "In an attempt to derive a median crossover crash rate, crashes were grouped together based on their roadway and county location. Crossover crashes for each segment were normalized by VMT to obtain a crossover median crash rate. The rates were plotted against the average median width for each segment. Figure 3 displays the 66 highway segment points and their average median width. Note that several highway segments exhibit noticeably high crossover crash rates in spite of large median widths. Thus, very little linear correlation was found between MCC rate and median width."

Figure 3 is inserted below. Note that the R-squared for the relationship between crossover crashes per VMT and median width is 0.01 – nearly zero. This indicates that for the 66 highway segments plotted, there is statistically ***no*** relationship between median width and the rate of crossover accidents.

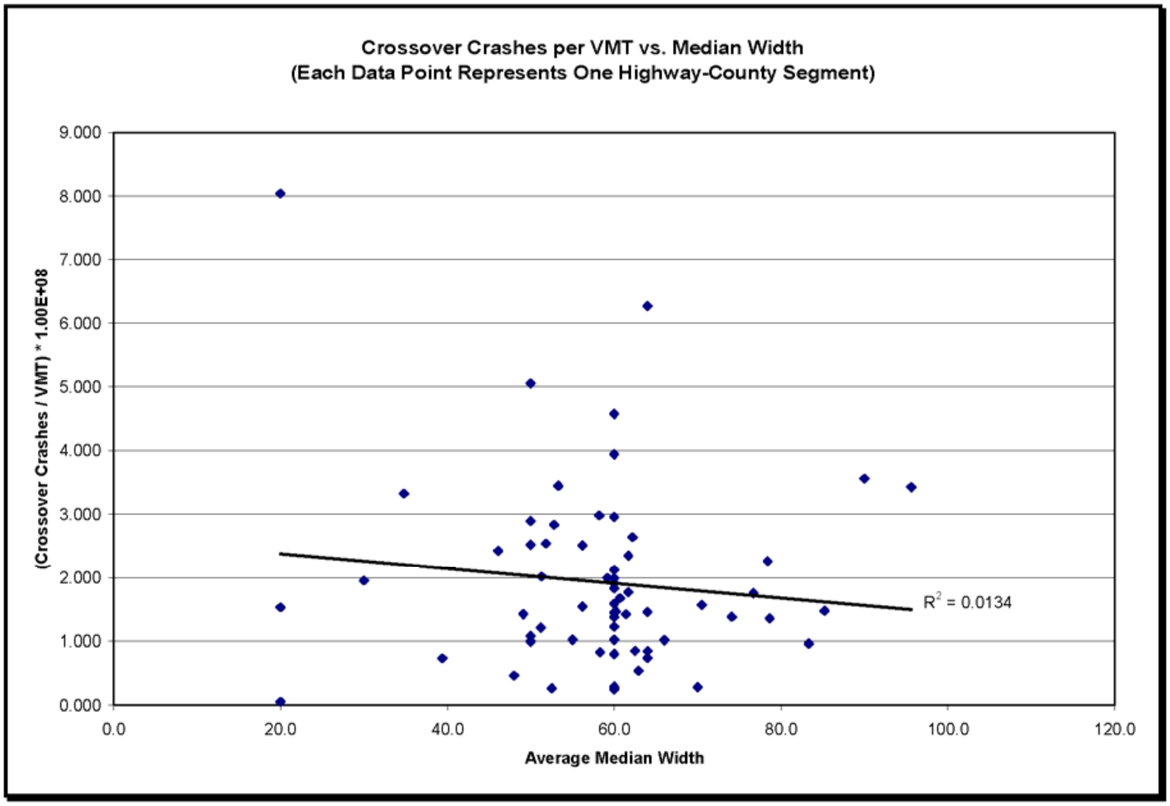

FIGURE 3 Crossover median crash rates vs. average median width.

Even though the regression line has a slight downward slope, its lack of statistical significance indicates that it may not be used as a predictive tool. Short of absolute randomness (R-squared ***exactly*** equal to 0), any analysis will produce *some sort* of a regression line. Its complete lack of significance indicates that its predictive power is nil.

This lack of a relationship between median width and crossover crashes is consistent with findings and statements in Knuitman and Hadi. Both make the point that the ability of median widening to affect crash rates "levels off" in the 60 – 80 foot range of median widths. The vast majority of the highway segments in this figure have median widths of at least 55 feet. It is not surprising for a specific type of crash (median crossover crashes) that analyzing highways with medians in this range shows that no relationship between median width and crashes.

The study did identify several factors as significant for forecasting MCCs. These included:

- Season of the year (winter weather months have higher rates of MCCs);
- Driver age (younger drivers have higher rates of MCCs);
- Roadway condition (at lower traffic volumes, icy roads have higher rates of MCCs); and
- EMS reaction time (has a significant relationship to fatal MCCs).

Conclusion. For a specific type of crash (median crossover crashes – MCCs), a three-year study found that there is no relationship between the rate of MCCs and median width. This is consistent with the fact that nearly all of the roadway segments studied have median widths of 55 feet or greater. Other studies have noted (for a wider range of crash types) that the relationship between median width and crash rates "levels off" in the 60 to 80 foot range.

Davis (2008)

This study's purpose is to provide the Minnesota Department of Transportation (MnDOT) with a framework for a cost-effectiveness ranking for cable barrier projects within specific highway sections. It determined that a direct statistical analysis[11] comparing factors such as traffic volumes and median width with median crossover crash rates were not suited to determining this cost-effectiveness ranking. Instead, it derives a simulation model using a Bayesian analysis with input factors provided by a Monte Carlo[12] simulation. The study results are the averages of the Monte Carlo simulations run a large number of times.

This basic equation used in this analysis is as follows:

$E[C] = E[N]P[U*N]P[X*U]P[C*X]$, where

$E[C]$ = expected number of median-crossing crashes/year
$E[N]$ = expected number of median encroachments/year
$P[U*N]$ = probability that an encroachment is uncontrolled
$P[X*U]$ = probability than an uncontrolled encroachment crosses the median
$P[C*X]$ = probability that a crossing encroachment collides with an opposing vehicle

$P[X*U]$ is a function of initial speed, deceleration across the median in the lateral direction, deceleration across the median in the longitudinal direction, a braking factor, and the median width.

$P[C*X]$ is determined by means of a user-defined traffic density, as well as the calculated trajectory of the vehicle after it leaves the median. This trajectory is calculated by numerically solving a system of ordinary differential equations, given the velocity and angle of travel calculated for the vehicle as it leaves the median.

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[11] A direct statistical analysis is the methodology used in all others studies reviewed in this memo.
[12] The term "Monte Carlo simulation" describes a large and widely-used range of methods. These methods have certain common characteristics. These are:

- A range or set of possible inputs is defined.
- Inputs are generated randomly and used in deterministic calculations.
- The process of randomly generating inputs and using them in deterministic calculations is repeated a large number of times to determine the final results.

The model parameters were estimated by using three years of accident data (2003 – 2005) from MnDOT's Highway Safety Information System. A total of 181 freeway segments were identified with at least one Median Crossing Crash (MCC) during this period (Appendix A). Of these 181 segments, 58 had variable widths, and no further information regarding their width was available to the researchers. Of the remaining 123 segments, ***none*** had medians wider than 60 feet.

Two points stand out from the preceding discussion. First, the methodology employed in this study uses median width in a very indirect way. It is one of several factors used to calculate one of four probabilities in a Bayesian analysis. By contrast, in the other papers reviewed in this document median width is an independent variable which is used directly to forecast crash rates.

Second, *no* freeway segments in the study sample have median widths greater than 60 feet. Any application of its results to freeway medians wider than 60 feet is not supported by the data.

The author states that median width *per se* is a poor predictor of median crossing crashes. On p. 12, he states, "Preliminary analyses using the year 2004 data indicated that while ADT and section length were reliable predictors of the number of median crossing crashes, median width was not, most likely due at least in part to the low variability in median widths for this sample."

In its Conclusion (p. 30), the author cautions that the results are not intended primarily to provide estimates of MCC frequencies. He states (emphasis is the author's), "*Although the model produces MCC frequencies that are roughly consistent with two published statistical models, we caution against treating the model as giving absolute estimates of MCC frequencies. Rather, the model should be used to compare the relative effectiveness of median treatments on different candidate highway sections.*"

Conclusion. This study uses a sample of freeway sections, none of which is wider than 60 feet. Any extrapolation of its results to median widths beyond 60 feet is not supported by its data. In addition, its stated purpose and application is to compare the cost-effectiveness of cable median barrier installations, not to compute rates or frequencies for MCCs.

Stamatiadis et al (2009)

This NCHRP report contains the findings of research performed to quantify the safety and operational impacts of design element trade-offs. It provides Accident Modification Factors (AMFs) for median widths on rural four-lane roads.

We were unable to identify where the report clearly stated whether its results were applicable to all rural multi-lane arterials, or only non-freeway facilities (those which are not fully access-controlled). It considers the effects of design features which are incompatible with rural freeways. These include lane widths ranging from 9 to 12 feet (Tables 1 and 2), paved shoulders ranging from 0 to 8 feet (Tables 5 and 6), and medians ranging from 15 to 90 feet (Table 8). The discussion of previous studies about the relationship between median width and safety states that certain studies were excluded because they dealt with freeway median widths.[13] In addition, the discussion of the multi-state database[14] used in this study described the 2,387 of roadway it included by stating, "All segments were classified as non-freeway, even though these facilities could qualify as rural multilane roadways and all have a length greater than 0.10 miles." (p. 19) Also, two of the facility characteristic variables used in the data analysis were presence of a left-turn lane, and functional class of the facility (whether or not the road was classified as a principal arterial). Thus while no explicit disclaimer was identified in the study which stated that it was applicable only to non-freeway facilities, it seems fairly clear that it is not directly applicable to the I-69 project[15]. Therefore, its results will not be further discussed.

However, the study provides two tables from other published research which show Accident Modification Factors (AMFs) for changes in median width for multi-vehicle crashes[16] on rural multi-lane divided roadways. Table S-3, cited from NCHRP Report 617 (Harkey, et al, 2008), shows an AMF of 0.945 for rural multilane roadways with 60-foot medians and no median barriers; for such roads with 84-foot medians it shows an (interpolated) AMF of 0.917. This implies that providing a 60-foot median instead of an 84-foot median would result in a 3.1% increase in the number of crashes. Table 8, cited from NCHRP Web-Only Document 126 (Lord et al., 2008), shows an AMF of 0.983 for rural multilane roadways with 60-foot medians and no median barriers; for such roads with 84-foot medians it shows an (interpolated) AMF of 0.971. This implies that providing a 60 foot median instead of an 84-foot median would result in a 1.1% increase in the number of crashes. We obtained copies of both NCHRP Report 617 and NCHRP Web-Only Document 126, but could not identify the sources of the data provided in Tables S-3 and 8. Thus, we cannot determine with certainty how applicable these AMFs are to rural freeways; however, they do indicate that providing a 60 foot rather than an 84-foot median on rural highways has a low to negligible effect (about 1 – 3%) on crash rates, which is consistent with other studies reviewed in this document.

Overall Findings

For Tier 2 engineering analyses, I-69 EEACs are being directed to apply alternative design criteria. One of these design criteria is median width. Specifically, alternative design criteria allow for either 60-foot or 84-foot medians for rural mainline I-69 sections.

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[13] "This (refers to Hadi's study, previously reviewed in this paper) is the only study that examined the effect of median width on safety for rural, multilane roads because the several studies reviewed by Hauer (33) and the NCHRP Project 17-27 interim report (21) deal with freeway median width." P. 21.

[14] Crash and highway inventory data used in this study's Phase II analysis were from California, Kentucky and Minnesota.

[15] A rural divided multi-lane rural road without full access control presents many safety issues which are avoided in a facility designed to freeway standards. These include left-turning vehicles, at-grade intersections, driveway access, and use by agricultural vehicles.

[16] The analysis assumes that median width has no effect on single-vehicle crash rates. P. 21.

A review of literature published over the last 15 years shows that there is little, if any, relationship between crash rates and the choice between 60- and 84-feet medians. Two of the applicable studies (Knuitman and Lu) show that an 84-foot median offers no added safety benefit as compared to a 60-foot median. A third study (Hadi) shows that there ***may be*** a safety benefit in the range of a 6% reduction in crash rates. However, this conclusion is based upon using the regression equations provided by the study; the data used to estimate these regression equations were not provided in the published findings. A fourth study (Tarko) has a very small sample size, and is applicable to median widenings where the initial median widths are in the range of 20 – 25 feet, or less. A fifth study (Donnell) provides data from Pennsylvania which shows a slight reduction in crash rates for an 84-foot median versus a 60-foot median. Applying its results in an "order of magnitude" analysis to Section 3 of I-69 shows annual user safety benefits of providing 84-feet medians of about $610,000, as compared to the cost savings of $12,000,000 to $18,000,000.[17] A sixth study (Davis) uses a data set with no freeway medians wider than 60 feet, making it inapplicable to this analysis. Further, this study analyzes median width in a very indirect fashion. A seventh study (Stamatiadis) analyzes only rural multilane roads which are not freeways, so its results are not applicable to the I-69 project. It does cite two other recent studies which show that providing an 84-foot median rather than a 60-foot median on rural multi-lane divided roads may cause a 1 – 3% increase in crash rates. However, these were referenced in such a way that it is not clear whether these rates apply to rural freeways.

Two other recently-published references on highway safety (TTI 2005 report and FHWA 2007 report) rely exclusively on Knuitman and Hadi for their forecasts of crash reduction due to changes in median width.

Based on this literature review and analysis, it is concluded that there is no significant safety benefit from providing an 84-foot median (as compared to a 60-foot median). One study (Hadi) suggests that there may be a slight benefit, corresponding to a reduction in crashes in the range of a few percent. One other study (Davis) suggests that the eventual annual user safety benefits (after the entire Indianapolis-to-Evansville project is completed) of an 84-foot median are about 3• - 5% of the project cost savings.

[17] Also, as noted in the discussion above, any project cost savings will be realized in the next 5 to 7 years. By comparison, the traffic forecasts underlying the user benefit calculations assume that I-69 is complete between Evansville and Indianapolis. Until this occurs, the safety benefits would be less than shown here.