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Using context classification to develop intersection Safety Performance Functions: national survey of current practices and evaluation of benefits for rural Florida intersections

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Abstract

The Highway Safety Manual (HSM) provides guidance for agencies on developing safety performance functions (SPFs) to predict traffic crashes. However, some states develop their own SPF methodologies due to data differences and a need for additional roadway categories. The Florida Department of Transportation has developed a context classification system that groups intersections into eight categories, allowing for the development of regional context-specific SPFs. To best utilize this system, safety engineers from departments of transportation (DOTs) across the United States were surveyed about their state's current SPF development practices and context classification. Many states (64% of the 42 respondents) use HSM SPFs or SPFs calibrated to their jurisdiction. Although 62% of states had not heard of context classification, 67% of states expressed interest in it. One reason some states were not interested in using context classification was insufficient evidence of its benefits compared to the current HSM methodology. To showcase the increased accuracy of SPFs developed using this system, HSM SPFs [baseline, baseline with crash modification factors (CMFs), and calibrated with CMFs] for rural two-lane, two-way roads were compared with a context-specific SPF for C2T-Rural Town signalized four-leg intersections. These comparisons found that the HSM SPF with CMFs overpredicted crashes for Florida intersections (calibration factor of 0.87). The context-specific SPF better predicted total crashes, contained additional variables (including a regional variable), and performed statistically better than all three HSM SPFs. By implementing a similar context classification system, agencies could develop more accurate SPFs and identify regional differences, improving safety throughout their jurisdictions.

Keywords - Safety Performance Functions, context classification, intersections, Highway Safety Manual, agency survey

1. Introduction

For transportation agencies across the United States (U.S.), reducing traffic crashes is a top priority. In 2017, there were 6,452,000 reported traffic crashes in the U.S., resulting in 37,133 fatalities and approximately 2,746,000 injuries [16]. State departments of transportation (DOTs) around the country share a vision of "towards zero deaths" for their roadway systems, aiming to eliminate fatalities and reduce serious injuries on all public roads by reducing crashes [7]. While some crashes can be attributed to driver error, other factors can affect the crash frequency that areas experience, including roadway design, geometry, and the environment/weather [3, 4, 14, 23]. Safety performance functions (SPFs) relate the number of crashes at a site to the characteristics of that site. These models typically include annual average daily traffic (AADT) and can include many other site characteristics like turn lane presence and traffic control [21]. SPFs are used primarily for three purposes: network screening to identify sites with potential for safety improvement, countermeasure comparison to determine how engineering treatments affect the baseline crash frequency, and project evaluation to determine crash modification factors (CMFs) using an observational before-after study [6].

In the Highway Safety Manual (HSM), baseline SPFs are developed for three primary facility types: rural two-lane roads, rural multilane highways, and urban and suburban arterials [1]. These baseline SPFs were developed only using data from a few states and represent an average site under base conditions, so they need to be calibrated to the jurisdiction being evaluated to obtain more accurate results [20]. CMFs can also be applied to these SPFs to account for site-specific features that deviate from the baseline values, modifying the predicted crash frequencies to make them more accurate for the studied sites. The HSM provides CMFs for various site-specific features, such as roadway shoulder width and lighting. Rather than calibrating the HSM SPFs to their jurisdiction, agencies could develop their own SPFs, allowing them to use their collected crash data and site information to make models specific for their area. Utilizing such a regional approach to SPF development could improve the accuracy of the developed SPFs, allowing state safety engineers to make well-informed decisions which can reduce crash frequency throughout various districts, counties, and cities.

Florida is one state which is developing its own SPFs rather than calibrating the HSM SPFs. To assist in this SPF development, the Florida Department of Transportation (FDOT) is utilizing its own context classification system that sorts roads into eight categories based on land use, development patterns, and roadway connectivity [8]. Using this system, FDOT can develop context-specific SPFs based on these eight context classification categories rather than calibrating the three categories used in the HSM. This allows for development of up to thirty-two SPFs (unsignalized and signalized 3-leg and 4-leg intersections in each context classification category), which is much more than the ten intersection SPFs developed in the HSM [1]. By considering these additional intersection groups, FDOT can better identify the unique influential variables and regional differences for the various classification categories and more accurately predict crash frequency for various land uses and intersection types. Preliminary context-specific SPFs were developed for two of these intersection groups in [12], showing the potential benefits of this system and its ability to identify regional differences.

The main goal of this paper is to understand current practices regarding development and implementation of regional SPFs using a survey sent to state DOT safety engineers across the U.S. This survey asked about the methodologies and current practices used to develop or calibrate SPFs in each state, as well as interest in using context classification for more accurate SPF development. The results of this survey showcase the current practices in SPF development as well as the national perception of context classification, which has not been previously researched. One finding of this survey was that safety engineers want to see the benefits of using context-specific SPFs compared to HSM SPFs. As such, another goal of this paper is to compare a context-specific SPF to respective HSM SPFs and show the increased predictive accuracy of using context-specific SPFs.

This paper first presents a literature review on SPF development and the results other states and jurisdictions have obtained using HSM SPFs or SPFs specific to their region. Next, the FDOT context classification system is described. Following this, information on the survey and the results of the survey are presented. Next, a context-specific SPF is developed and compared with the HSM SPFs. Lastly, a summary of the work and conclusions based on the results are provided, including limitations and potential for future research.

2. Literature review

The HSM provides baseline SPFs, but these need to be calibrated to the studied jurisdiction to be more accurate. Calibration factors represent the ratio of observed crashes to predicted crashes, with values greater than one indicating that the observed number of crashes exceeds the predicted number of crashes [1]. The HSM recommends that a jurisdiction's SPF calibration factors be recalculated every two to three years, with some users opting for annual recalibration [1]. Research suggests that the frequency at which recalibration should occur for intersections is a function of the total number of crashes, the AADT of major and minor roads, and the number of intersections in the study area [19]. Regardless of calibration frequency, predictions of the calibrated SPFs for individual intersections can still differ greatly from the observed values, suggesting that the calibrated HSM SPFs might not be the most accurate models for all situations.

To improve SPF accuracy, several states have opted to develop their own SPFs instead of using calibrated SPFs. In Tennessee, the statewide calibration factor for rural two-lane, two-way road segments was 2.48, suggesting that the HSM SPF greatly under-predicted the crash frequency on Tennessee roads [22]. Evaluations showed that a fully specified Tennessee-specific random parameter Poisson SPF outperformed all other SPFs [22]. Similar results were found in other states such as Utah, where the HSM SPF for rural two-lane, two-way roads also underpredicted the observed number of crashes [2]. A state-specific negative binomial model with log-transformed AADT provided more accurate results [2]. In a study of Michigan rural segments and intersections, the calibrated HSM SPFs had significant variability in terms of goodness-of-fit across various site types, due in part to the high proportion of deer crashes on rural Michigan highways [13]. When developing SPFs specific to Michigan, a simple statewide model based on AADT was developed alongside regionalized models that included factors about drivers, weather, and topography [13]. These regionalized models provided more accurate results than the calibrated HSM SPFs [13]. Pennsylvania has also developed regionalized SPF model adjustments at the district and county levels [5]. Using the same three facility types as the HSM, SPFs were developed for roadway segments and intersections, including a district-level SPF with county-level adjustments and a statewide SPF with district-level adjustments [5].

Synthesizing the methodologies and results of SPF development and implementation across the U.S. can provide useful insights which could improve safety throughout the nation. Some previous efforts have been made to determine the degree of HSM implementation and usage in different states, particularly regarding the use of the predictive methods that guide SPF development. The NCHRP, at the request of AASHTO, conducted a national scan of states that at least partially implemented the HSM to determine leading practices in its usage [17]. The ten participating state agencies discussed how they implemented the HSM in their state, including how they use SPFs. Some states, such as Illinois, used their state-specific SPFs to establish a roadway safety rating system while other states, such as Louisiana, used the predictive methods for establishing calibration factors [17]. However, implementation of the HSM can be difficult for some states. In a study of how to apply the HSM to Georgia, two surveys were administered to other state agencies to understand the degree of HSM implementation [18]. The first survey asked 14 states about their plans for the implementation of the HSM in their jurisdictions. The results of this survey suggested that there were issues with the availability and quality of data needed to conduct analyses [18]. The second survey, which was administered a few years after the first, asked 41 states about how they implemented the HSM and for which purposes they used it. Overall, 34 of these states had plans to change how their agency used the HSM and 29 found deficiencies in the HSM, including that it did not contain enough distinct roadway types and that the calibration process was long and difficult to follow [18].

The previous research generally focused on the development of SPFs for a specific state as well as how states are implementing the HSM and potential issues or difficulties. A major gap in this previous research is a lack of study on alternative methodologies, such as a new classification system, which could improve SPF accuracy and address some of the issues with the HSM. One of the main concerns was that the HSM does not cover enough different roadway types. The FDOT context classification system could be an alternative to the HSM for those states who wish to have more roadway type options beyond the HSM's three categories. This system would also allow agencies to develop their own SPFs rather than following the potentially confusing HSM calibration process. This paper proposes a regionalized approach to SPF development using context classification which fills the gap in previous research and could provide practitioners with multiple SPFs for various site types while also revealing which regions could use additional improvements compared to other regions in the study area. The survey discussed in this paper is the first to survey state agencies about their perception of and interest in using context classification for SPF development. It also shows potential issues that might need to be resolved before an agency considers using this system. One of these issues is lack of evidence showing the benefits of this system compared to the HSM methods. To address this issue, this paper compares the predicted crashes from HSM SPFs to predicted crashes from a context-specific SPF, which has never been done before.

3. FDOT context classification system framework

FDOT introduced the context classification system as part of its Complete Streets initiative, which is designed to serve the transportation needs of users of all ages and abilities, including pedestrians, bicyclists, and freight handlers [9]. The context classification system guides the planning, design, construction, and maintenance of a road in order to ensure that the road remains contextually compatible to the nearby developments while still supporting safe travel for all users. Effective in 2018, the context classification system has been integrated into the FDOT Design Manual (FDM) to establish appropriate design criteria which help serve the users of that area [9]. For example, urban areas have lower design speeds and wider sidewalks compared to less urbanized areas, reflective of how the well-connected roadway network of urban areas has more pedestrians, bicyclists, and transit users than suburban or rural areas [10, 11].

The context classification system (shown in Figure 1) uses eight categories based on land use characteristics, roadway connectivity, and development patterns: C1-Natural, C2-Rural, C2T-Rural Town, C3R-Suburban Residential, C3C-Suburban Commercial, C4-Urban General, C5-Urban Center, and C6-Urban Core [8]. This context classification system is based on analytical measurements that evaluate distinguishing characteristics, primary measures (such as roadway connectivity), and secondary measures (such as population density) [8]. Roadway segments and intersections must meet many of the primary measures in order to be classified as that context, with secondary measures being used to help further define the context when there is not a clear result from analysis of the primary measures [8]. This context classification system complements the existing roadway functional classification.

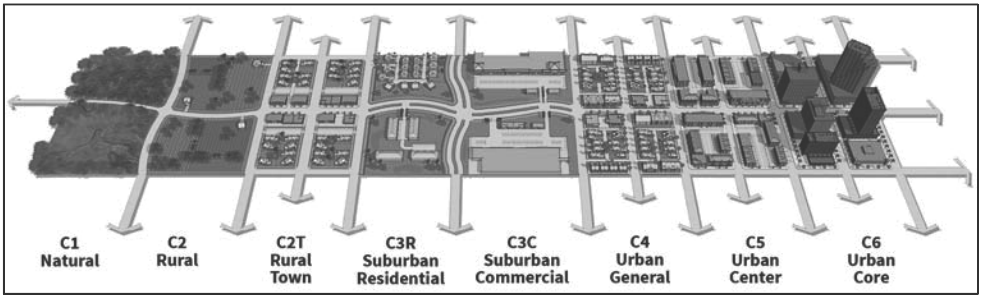

Fig. 1 - FDOT context classification zones [8]

Due to the unique characteristics of each context classification, crash risks and crash factors can vary between them. For instance, areas with increased pedestrian traffic (such as C4-Urban General, C5-Urban Center, and C6-Urban Core) likely experience more pedestrian-related crashes compared to areas with less pedestrian traffic, such as C1-Natural. Identifying the context classification can help safety engineers determine the appropriate actions necessary to ensure that the users of that facility remain safe. This system allows for development of up to 32 intersection group SPFs based on context classification, number of legs, and signalization (depending on data availability and sample size). Developing SPFs for each of these intersection groups can provide safety engineers with detailed insights into the specific needs of each intersection group.

This context classification system also allows for development of regional SPFs, since intersections within the same region often have similar context classifications and certain classifications which are closely related (such as C2-Rural and C2T-Rural Town) often appear near each other. The insights gleaned from the context-specific SPFs can help safety engineers better understand the unique conditions of that region based on which factors for a classification or region are significant in the developed SPF model. Understanding the methodologies and practices safety engineers in other states use for SPF development can help make these regional context-specific SPFs more robust and accurate, making it more likely for other states to consider adopting a similar system.

4. State DOT SPF current practices survey

The state DOT SPF current practices survey was developed by the authors with input from FDOT and designed to be taken online. The survey was hosted on a third party website and sent to contacts from 51 DOTs (all 50 states plus District of Columbia). By the end of the survey's availability window, 42 state-designated safety engineers or similar professionals (state traffic engineers, research coordinators, etc.) had completed the survey. The survey was only sent to the state-designated safety engineer or similar professional in order to understand the state's official current practice.

The questions, response choices, frequencies, and response percentages to the multiple-choice questions for the 42 completed surveys are shown in Table 1. The open-ended responses are discussed in the following sections. Some questions had fewer than 42 responses since they were only asked to respondents who selected certain responses to previous questions. The percentages shown in Table 1 were rounded to the nearest whole percent, so some percentages might not sum to 100%. The most frequently chosen response for each question is shown in bold.

Tab. 1 - State DOT SPF survey questions and responses (continue)

Question	**Response Choices**	**Frequency**	**Response Percentages**
Prior to this survey, had you heard about Florida or other states using context classification to develop SPFs? (See Figure 2)	Yes	16	38%
	No	**26**	**62%**
Please select one of the following options which best describes how your agency currently develops SPFs for intersections. (See Figure 3)	Uses default SPFs provided in the Highway Safety Manual (HSM).	9	21%
	Uses the HSM methodology to develop jurisdiction-specific SPFs for your agency using calibration factors.	**18**	**43%**
	Uses a non-HSM methodology developed by your agency.	6	14%
	Uses a non-HSM methodology developed by another agency.	1	2%
	Does not develop SPFs for intersections.	8	19%
Why does your agency use a non-HSM methodology to develop SPFs?*	HSM procedures were not rigorous enough.	0	0%
	HSM procedures were insufficient.	2	29%
	State had specific requirements that HSM did not account for.	2	29%
	Other methods provided more accurate results.	3	43%
	Other	**4**	**57%**
Does your agency currently use a system similar to the FDOT Context Classification system to develop SPFs?	Yes	1	14%
	No	**6**	**86%**
Is your agency currently planning to develop SPFs in the future?	Yes, using a similar approach to the FDOT Context Classification System shown in Figure 1.	0	0%
	Yes, using the Highway Safety Manual (HSM) methodology or similar approach.	**6**	**75%**
	No	2	25%
Is your agency currently investigating ways to improve its methodology to develop SPFs?	**Yes**	**19**	**58%**
	No	14	42%
Does your agency have any interest in using context classification or a similar system to develop SPFs? (See Figure 4)	**Yes**	**26**	**67%**
	No	13	33%
Does your agency currently have any plans to implement context classification or a similar system in the future?	Yes	8	38%
	No	**13**	**62%**

Question	Response Choices	Frequency	Response Percentages
When did your agency first start using context classification or a similar system for the development of SPFs?	1 – 6 months ago	0	0%
	6 months – 1 year ago	0	0%
	More than 1 year ago	**1**	**100%**
Has your agency witnessed an improvement in safety measures after the implementation of this system?	**Yes**	**1**	**100%**
	No	0	0%
	Unknown	0	0%

*Respondents could select multiple responses to this question.

4.1. Initial questions

The initial questions of the survey were asked to all 42 survey respondents. These questions asked about the survey respondents' awareness of context classification and how their states develop SPFs. Respondents were provided with a description of the FDOT context classification system along with an image similar to Figure 1 which showed each context classification and its defining attributes. Figure 2 shows specific state responses to this question.

The second question in this section asked respondents how their agency currently develops SPFs for intersections. Nine respondents (21%) use the default SPFs provided in the HSM without modification, eighteen (43%) use the HSM methodology to develop jurisdiction-specific SPFs with calibration factors, six (14%) use a non-HSM methodology developed by their own agency, one (2%) uses a non-HSM methodology developed by another agency, and eight (19%) do not develop any intersection SPFs. Specific state responses to this question are shown in Figure 3. Many of the states who calibrate their SPFs are in the midwestern and southern regions of the U.S., possibly indicating that the base HSM SPFs do not accurately model traffic and roadway conditions in these states. This could be due to aspects noted previously in the literature, such as a high proportion of animal crashes in Michigan, or other features (such as weather). Several states that do not develop SPFs might not have enough sites or crashes for analysis due to having lower populations, such as Alaska and Idaho. Based on the responses to this question, respondents were directed to different parts of the survey.

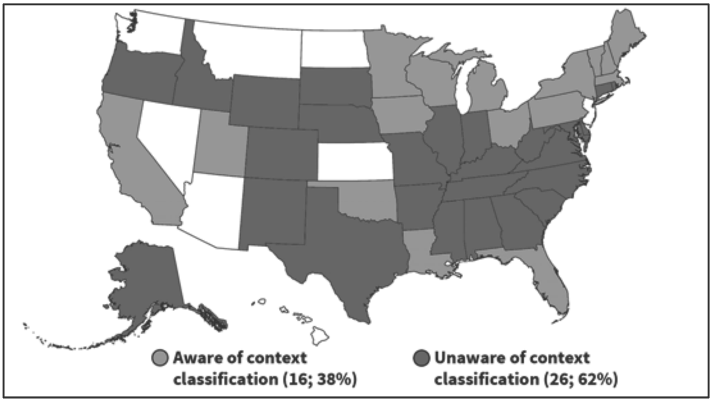

Fig. 2 - State DOT survey respondents' awareness of the use of context classification for SPF development

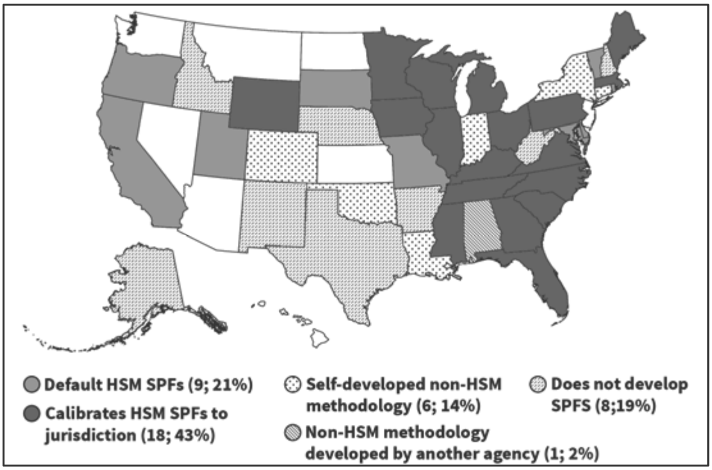

Fig. 3 - Intersection SPF development methodologies for state DOT survey respondents

4.2. Questions for States which use non-HSM methodologies

The seven respondents from states which use a non-HSM methodology were next asked why their state uses a non-HSM methodology to develop their SPFs. Multiple answer choices were provided, with respondents being able to select all answer choices that applied. Zero respondents said that the HSM procedures were not rigorous enough, two respondents said the HSM procedures were insufficient, two respondents said their state had specific requirements that the HSM did not account for, and three respondents said that other methods provided more accurate results. Additionally, four respondents specified other reasons why they use a non-HSM method, with the most notable response stating that both planning- and project-level SPFs were needed. These responses suggest that, while the HSM might be rigorous enough with its methodology for SPF development, it does not adequately meet the needs of all states. These needs are reflective of the unique regional differences in each state, such as various terrains or higher proportions of certain crash types, as well as regional needs for more specific types of SPFs for different applications. Developing regionalized SPFs can help to address the needs of these states who use a non-HSM methodology.

Next, these seven respondents were asked if their state uses a system like the FDOT context classification system to develop SPFs. Only the respondent from Oklahoma answered “Yes” to this question. The remaining six respondents from Alabama, Colorado, Connecticut, Indiana, Louisiana, and New York who answered “No” were then asked to describe the non-HSM methodology their state uses to develop SPFs. Analysis of the responses to this open-ended question showed that these states generally use another form of classification that primarily relies on roadway characteristics, such as functional class of the road, lane count, and whether it is located in a rural or urban setting.

4.3. Questions for States which do not develop SPFs

The eight respondents from states which do not develop SPFs were asked the questions in this section. These respondents were first asked to describe why their state does not develop SPFs for intersections. Five respondents answered that their states either lack the resources or the data to accurately create or use SPFs. Two respondents stated that their states are working on developing their SPFs and currently do not use them since they are early in development. The last respondent stated that their state only uses SPFs for network screening and not for intersections. Next, these respondents were asked if they plan on developing SPFs in the future, of which two answered “No” and the remaining six answered that they plan to use the HSM methodology or a similar approach. No respondent in this section expressed an interest in using a similar approach to FDOT context classification system. The context classification system allows for a more regionalized approach to SPF development that can make accurate models for specific areas rather than a statewide model. It would be worthwhile to follow up with these six states that plan to use an HSM methodology for SPF development to see how accurate their state model results are and if they would eventually want to consider context classification instead. The survey ended for the two respondents who answered “No” to this last question, while the survey continued for the other six respondents.

4.4. Questions for States which do not use context classification to develop SPFs

The questions in this section of the survey were asked to respondents who previously said that their state does not use context classification or a similar method. The first question in this section was asked to the 27 respondents who use HSM SPFs or the HSM methodology, along with the six respondents who use a non-HSM methodology in Figure 3 (excluding Oklahoma) but do not use a context classification system. These 33 respondents were asked if their state is investigating ways to improve their SPFs; 19 respondents (58%) said “Yes” and 14 respondents (42%) said “No”. The 19 respondents who said “Yes” elaborated on what improvements their states are working on, with many focusing on developing/improving calibration factors or finding the optimal ways to segment roadways to get the most accurate SPFs. Some are in the process of developing regionalized approaches that include more data and more diverse segmentation of SPFs. A few notable responses indicated that some states are looking at new data and innovative methods to develop SPFs. Connecticut is planning to use driver and vehicle information, driveway density, and minor roads without AADT in developing SPFs; Louisiana is intending to include crash collision manner information in their models; and Virginia is studying the use of artificial intelligence and neural networks to automatically scan roadways to collect data.

The next question asked respondents if their state has an interest in using context classification to develop SPFs. This question was asked to the 33 respondents who answered the first question in this section about improving their SPF development methodology, plus the 6 respondents whose states do not currently develop or use SPFs but plan to develop SPFs in the future using the HSM methodology. Out of these 39 respondents, 26 respondents (67%) expressed an interest in eventually using a system like context classification (individual state responses shown in Figure 4). The 13 respondents who did not express an interest in using context classification were then asked why they were not interested in this type of system. Common reasons for a lack of interest in context classification included insufficient evidence of the benefits of using this system over the current HSM methodology; states are busy developing their own SPFs using HSM or their own methods; issues with unreliable, missing, or unorganized data; and worry that the complexity of rolling out a new system could intimidate their local agencies and prevent widespread adoption. After this question, the survey ended for the 13 respondents who were not interested in using context classification plus the five respondents from the states which do not currently develop SPFs who answered “Yes” to having an interest in using context classification or a similar system to develop SPFs.

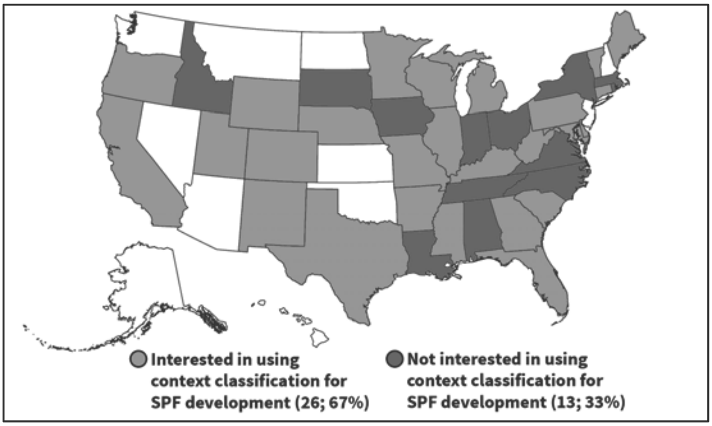

Fig. 4 - State DOT survey respondents' interest in using context classification for SPF development

The remaining 21 respondents were asked if their state had any plans to implement context classification, of which 13 respondents (62%) answered "No". The survey ended for these thirteen respondents, while the eight respondents who answered "Yes" were asked to explain what kind of system they planned on implementing. One notable response was from Pennsylvania's respondent, who stated that Pennsylvania is breaking down SPFs into individual engineering districts and counties. Other respondents noted that their states are studying the use of functional classification or simple context zones to develop SPFs. This was the last survey question for these eight respondents.

4.5. Questions for States which use context classification to develop SPFs

The last three questions were asked to the respondents who said their state currently uses a system like FDOT's context classification system. Only the respondent from Oklahoma was directed to this section. Oklahoma's context classification system is a terrain-based system that accounts for rolling hills, flat terrain, rock, and various urban classifications. These classifications are used in conjunction with a breakdown of areas into rural or urban. The system was implemented over one year ago and there has been an improvement in safety measures after implementing this terrain-based classification system. This response suggests that the use of context classification systems can result in safety improvements. Therefore, it is likely that other agencies can achieve similar safety improvements using a context classification system for regional SPF development.

5. Comparisons of HSM SPFs with a context-specific SPF for Florida

Several of the surveyed state safety engineers who did not express an interest in adopting context classification stated that there was insufficient evidence of the benefits of using context classification over their current approaches. To illustrate the benefits of using a context classification system for SPF development, comparisons were made between a context-specific SPF for C2T-Rural Town signalized four-leg intersections in Florida and three types of HSM SPFs for rural two-way, two-lane signalized four-leg intersections: the base HSM SPF, the base HSM SPF with CMFs, and a calibrated HSM SPFs with CMFs. Only two-way, two-lane intersections in the C2T-Rural Town signalized four-leg group were considered to allow for accurate comparisons with the HSM SPFs. There were 31 two-way, two-lane intersections in this group. Total crash data from 2013, 2014, and 2015 were used for these comparisons, with the minimum number of crashes per year being 101 in 2013. Therefore, the studied intersection group meets the HSM recommended sample sizes of at least 30 sites and at least 100 crashes per year [1].

5.1. Data collection and preparation

The intersection data used in these comparisons were collected in accordance with the Model Inventory of Roadway Elements (MIRE) 2.0 data standard published by FHWA [15]. These data were collected for 28 potential predictor variables, which include a regional variable to identify FDOT districts that have significantly different crash frequencies than other districts. Data were sourced from existing FDOT data or collected by the authors using satellite imagery and Google Street View data. Collected data were verified independently by at least three coauthors. Descriptions of all considered variables can be found in [12]. Since minor AADT was not available for all intersections in the studied group, a minor AADT linear regression model was developed by the authors using data from 719 intersections with available minor AADT across all context classification categories. This minor AADT model is shown in Equation 1. All included variables were significant at 5% significance level. The model had an adjusted R^2 of 0.62 and a Mean Absolute Percentage Error (MAPE) of 6.21%. Predicted minor AADT values from this model were used for intersections with unavailable minor AADT, while the true minor AADT volumes were used at intersections where these volumes were available.

$$\begin{aligned}&\ln(AADT_{min}) = 3.059 + 0.472\ln(AADT_{maj}) +\\ &0.00089(Major\ Exclusive\ Left\ Turn\ Length) +\\ &0.349(Minor\ Exclusive\ Left\ Turn\ Number) +\\ &0.336(Minor\ Exclusive\ Right\ Turn\ Number) + 0.170(Minor\ Through\ Lanes) -\\ &0.023(Speed\ Limit\ Major) + 0.0095(Speed\ Limit\ Minor) + 0.149(Major\ Median) -\\ &0.346(Functional\ Class\ Minor = Local\ Road) - 0.592(Functional\ Class\ Minor =\\ &Collector\ Road)\end{aligned} \tag{1}$$

where:
$AADT_{min}$ = AADT on the minor road in vehicles per day; and
$AADT_{maj}$ = AADT on the major road in vehicles per day.

5.2. Determining SPFs using the HSM procedures

The base HSM SPF for four-leg signalized intersections on rural two-lane, two-way roads is shown in Equation 2 [1]. This base SPF is used to predict the expected crash frequency for each studied intersection. These predicted values can then be multiplied by various CMFs to account for the individual intersection characteristics. The HSM outlines four CMFs that can be used for this specific SPF: intersection skew angle, intersection left-turn lanes, intersection right-turn lanes, and lighting. For the first three CMFs, the values and procedures outlined in the HSM were used. The lighting CMF required calculation of the proportion of crashes at unlit intersections which occurred at night. This calculated proportion of 0.274 was used instead of the HSM's default value of 0.286. With values for all four CMFs calculated for each intersection, a new set of predicted crash frequencies was determined.

$$N = \exp\left(-5.13 + 0.60 \ln AADT_{maj} + 0.20 \ln AADT_{min}\right) \quad (2)$$

where:
N = SPF estimate of intersection-related predicted average crash frequency for base conditions.

The final HSM SPF considered was a calibrated SPF with CMFs. For the base SPF with CMFs, the total predicted crash frequency for all 31 intersections was 379.02, while the actual number of crashes was 331. This resulted in a calibration factor of 0.87. Multiplying this calibration factor by each intersection's predicted crash frequency provided a third set of prediction values.

5.3. Determining the context-specific SPF

The collected data were used to fit a negative binomial model to the C2T-Rural Town signalized four-leg intersection group. All 70 intersections in this group were modeled, with only the predictions for the two-way, two-lane intersections used for comparison with the HSM SPFs. The context-specific SPF for C2T-Rural Town signalized four-leg intersections is shown in Table 2. This context-specific SPF shows that both the major and minor AADT have a positive relationship with the number of crashes, which indicates that increased traffic at an intersection increases the number of crashes. This agrees with the base HSM SPF. The lighting variable has a negative relationship with crash frequency (intersections with lighting are expected to have fewer crashes than intersections without lighting), which agrees with the lighting CMF in the HSM. The lighting variable is binary, with a value of 1 if lighting is present at an intersection and 0 if not. The final significant variable in the context-specific SPF is the district variable, which has a negative coefficient for FDOT District 3. This means that intersections from this group in District 3 are expected to have fewer crashes compared to intersections from this group in other districts. District 3 contains 21 of the 70 modeled intersections for this group, with 12 of these being two-way, two-lane intersections. Including this variable allows FDOT to identify the improved safety of District 3 intersections so they can be studied in more detail and effective treatments applied to other districts.

5.4 Comparison of performance measures

Several performance measures were evaluated to compare the prediction performance of the three developed HSM SPFs with the context-specific SPF for the studied intersections: Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), and MAPE. All three of these performance measures provide insight on the differences between the observed values and the predicted values. Lower values of these performance measures indicate better performing models. The results of these comparisons are shown in Table 3.

Tab. 2 - Negative binomial context-specific SPF for C2T signalized four-leg intersections

Variable	**Estimate**	**Standard Error**	**p-value**
Intercept	-3.939	2.015	0.0506
$\ln AADT_{maj}$	0.396	0.221	0.0731
$\ln AADT_{min}$	0.413	0.124	0.0008
Lighting	-0.814	0.447	0.0685
District = 3	-1.472	0.326	<0.0001

Tab. 3 - Performance measures of HSM SPFs and C2T signalized four-leg context-specific SPF

Safety Performance Function	**MAE**	**RMSE**	**MAPE**	**Predicted Crashes**
Base HSM SPF	7.169	12.560	92.6%	210
HSM SPF with CMFs	9.445	12.500	197.3%	379
Calibrated HSM SPF with CMFs	8.887	12.401	168.5%	331
C2T Signalized Four-Leg Context-Specific SPF	5.410	10.372	70.2%	296

Based on these comparisons, the context-specific SPF outperformed each of the HSM SPFs in all three performance measures. Additionally, the predicted crash total from the context-specific was closer to the actual total of 331 crashes than the predicted totals from the non-calibrated HSM SPFs. This indicates that the context-specific SPF was able to predict crash frequencies more accurately than the HSM SPFs. Additionally, the base HSM SPF performed better than the HSMs with CMFs, suggesting that the CMFs included in the HSM might not be accurate for Florida. Overall, this comparison provides evidence of the potential benefits of developing SPFs using context classification, which addresses one of the main reasons why some states are not interested in implementing such a system.

6. Summary and conclusions

Traffic crashes are a major safety concern for DOTs around the U.S. To aid in safety analysis, the HSM provides baseline SPFs and CMFs for state agencies to use in crash frequency predictions. However, these SPFs and CMFs were developed with data from select states, so they might not be accurate for all states and the regions within them. These provided models and factors need to be calibrated for a specific jurisdiction in order to more accurately predict crash frequency, but this calibration process can be tedious. Due to these reasons and the need to consider additional roadway types, some agencies are developing their own jurisdiction-specific SPFs. These SPFs are more tailored to the state or region compared to calibrated HSM SPF, which can make them more appealing to state safety engineers who want to accurately predict crash frequency in specific regions. Developing regionalized SPFs allows safety engineers to better understand the unique differences in crashes across regions of their state, which the HSM SPFs cannot determine. FDOT's context classification system, which divides roadway segments and intersections into eight categories, can be an alternative to the HSM for states who want to develop regional SPF models. FDOT is currently developing intersection SPFs based on this context classification system, which could result in SPFs for more intersection types than the HSM and that are more accurate than calibrated HSM SPFs due to the consideration of state-specific data and unique regional elements.

To help develop these regional context-specific SPFs, an online survey of state safety officials from DOTs across the U.S. was conducted. Out of the 42 states who responded to the survey, 62% had not heard about FDOT's context classification system. However, 67% of respondents expressed interest in eventually adopting a similar system. Concerns that were raised about adopting such a system were lack of evidence of its benefits, data collection requirements and necessary resources, and how to handle unreliable or missing data. Most survey respondents (64%) said their states either use SPFs directly from the HSM or SPFs that have been calibrated to their jurisdiction based on the HSM SPFs. Many states are looking at ways to improve their SPFs, typically by calibrating their existing models rather than creating new ones. Seven respondents said their states uses non-HSM methodologies to develop SPFs, typically because their models give more accurate results due to the HSM methodology lacking a specific variable or attribute that was important to their state. These non-HSM SPFs tend to focus on functional class, lane count, and whether the intersection is in a rural or urban environment.

The open-ended questions of the survey showed that a few states are using or investigating innovative ways to develop SPFs. Oklahoma uses a system similar to context classification which is based on the terrain of the landscape (rolling hills, rocky, flat, urban, etc.) rather than land use. This system was implemented over a year ago and has resulted in safety improvements, which suggests promising potential for the FDOT context classification system. Other states, including Connecticut and Louisiana, are working on including more data in their SPFs, such as driver information, vehicle information, and collision manner. Additionally, Virginia is investigating the use of artificial intelligence and neural networks to automatically scan roadways and acquire data for modeling.

To help show the benefits of using context classification for SPF development, a context-specific SPF was developed and compared to HSM SPFs. Following the HSM procedures, a base SPF, SPF with CMFs, and a calibrated SPF with CMFs were determined. These SPFs were used to predict crashes for two-way, two-lane intersections in the C2T-Rural Town signalized four-leg intersection group. The context-specific SPF developed for this intersection group contained a regional variable for FDOT District 3, indicating that intersections from this group located in this district have fewer crashes than similar intersections in other FDOT districts. Comparing the three HSM SPFs (base SPF, SPF with CMFs, and calibrated SPF with CMFs) with the context-specific SPF showed that the context-specific SPF more accurately predicted crashes than the HSM SPFs since the context-specific SPF had the lowest value for all three performance measures (MAE, RSME, and MAPE). These findings show the benefits of the context classification system (better performance than the HSM SPFs and identification of regional differences in Florida), which can help address some agencies' concerns in considering such a system. One limitation of this research was having to predict AADT for roads that did not have it available, as collected data would be preferred over predicted data. Moreover, a larger sample size of C2T-Rural Town intersections would help provide a more accurate model.

The research discussed in this paper shows that many states are interested in the use of context classification to develop SPFs, even if they are not currently planning on implementing such a system. Creating easy-to-use models based on context classification can encourage adoption by local agencies. However, an agency would first need to develop or adopt a context classification system and collect data based on that system to develop context-specific SPFs. Further research is needed to see if the benefits identified in this paper apply to urban intersection groups. Guidelines are also needed on efficient data collection practices and procedures to handle unreliable or missing data. By addressing the concerns identified by the survey discussed in this paper, such as insufficient evidence of benefits and lack of data availability or resources to collect data, agencies could be more likely to use context classification in the future. This increased usage of a context classification system could improve the accuracy of SPFs and allow for improved safety throughout the U.S.

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References

1. American Association of State Highway and Transportation Officials (2010). *Highway Safety Manual (1st ed.).*
2. Brimley, B. K., Saito, M., Schultz, G. G. (2012). Calibration of Highway Safety Manual Safety Performance Function: Development of New Models for Rural Two-Lane Two-Way Highways. *Transportation Research Record: Journal of the Transportation Research Board*, 2279, pp. 82-89. DOI: 10.3141/2279-10
3. Call, D. A, Medina, R. M., Black, A. W. (2019). Causes of Weather-Related Crashes in Salt Lake City, Utah. *The Professional Geographer*, 71, pp. 253-264. DOI: 10.1080/00330124.2018.1501713
4. Choi, E (2010). *Crash Factors in Intersection-Related Crashes: An On-Scene Perspective*. Publication DOT HS 811 366, National Highway Traffic Safety Administration, U.S. Department of Transportation.
5. Donnell, E., Gayah, V., Li, L. (2016). *Regionalized Safety Performance Functions*. Publication FHWA-PA-2016-001-PSU WO 017, Pennsylvania Department of Transportation.
6. Federal Highway Administration (2014). *Introduction to Safety Performance Functions*. Publication FHWA-SA-13-016, Federal Highway Administration, U.S. Department of Transportation.
7. Federal Highway Administration (2018). *FHWA FY 2019-2020 Strategic Plan*. https://www.fhwa.dot.gov/policy/strategicplan/safety.cfm.
8. Florida Department of Transportation (2017). *FDOT Context Classification*. https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/roadway/completestreets/files/fdot-context-classification.pdf.
9. Florida Department of Transportation (2018). *Complete Streets Handbook Brochure*. https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/roadway/completestreets/files/fdot-completestreets-brochure.pdf.
10. Florida Department of Transportation (2018). *FDOT District Five Complete Streets & Context Classification*. https://www.r2ctpo.org/wp-content/uploads/Context-Classification-Presentation.pdf.
11. Florida Department of Transportation (2019). *FDOT Design Manual: Design Criteria*. Publication 625-000-002, Florida Department of Transportation.
12. Gamaleldin, G., Al-Deek, H., Sandt, A., El-Urfali, A., Kayes, M. I., Gamero, V. (2020). Roadway Context Classification Approach for Developing Regional Safety Performance Functions for Florida Intersections. *Transportation Research Record: Journal of the Transportation Research Board*, 2674, pp. 191-202. DOI: 10.1177/0361198120906377
13. Gates, T., Savolainen, P., Avelar, R., Geedipally, S. R., Lord, D., Ingle, A., Stapleton, S. (2018). *Safety Performance Functions for Rural Road Segments and Rural Intersections in Michigan.* Publication SPR-1645, Michigan Department of Transportation.
14. Geedipally, S. R., Pratt, M., Lord, D. (2019). Effects of Geometry and Pavement Friction on Horizontal Curve Crash Frequency. *Journal of Transportation Safety & Security*, 11, pp. 167-188. DOI: 10.1080/19439962.2017.1365317
15. Lefler, N., Zhou, Y., Carter, D., McGee, H., Harkey, D., Council, F. (2017). *Model Inventory of Roadway Elements – MIRE 2.0*. Publication FHWA-SA-17-048. Federal Highway Adminstration, U.S. Department of Transportation.
16. National Center for Statistics and Analysis (2019). *Summary of Motor Vehicle Crashes: 2017 Data*. Publication DOT HS 812 794, National Highway Traffic Safety Administration, U.S. Department of Transportation.
17. National Cooperative Highway Research Program (2018). *Leading Practices in the Use of the Highway Safety Manual for Planning, Design, and Operations*. http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-68A_16-01.pdf.
18. Rodgers, M. O., Wilson, A. M., Shaw, A., Barton, M. T. (2015). *Applying the Highway Safety Manual to Georgia.* Publication FHWA-GA-15-1215, Georgia Department of Transportation.
19. Shirazi, M., Geedipally, S. R., Lord, D. (2017). A Procedure to Determine when Safety Performance Functions Should be Recalibrated. *Journal of Transportation Safety & Security*, 9, pp. 457-469. DOI: 10.1080/19439962.2016.1240734

20. Srinivasan, R., Carter, D., Bauer, K. (2013). *Safety Performance Function Decision Guide: SPF Calibration vs SPF Development*. Publication FHWA-SA-14-004, Federal Highway Administration, U.S. Department of Transportation.
21. Srinivasan, R., Bauer, K. (2013). *Safety Performance Function Development Guide: Developing Jurisdiction-Specific SPFs*. Publication FHWA-SA-14-005, Federal Highway Administration, U.S. Department of Transportation.
22. Wali, B., Khattak, A. J., Waters, J., Chimba, D., Li, X. (2018). Development of Safety Performance Functions: Incorporating Unobserved Heterogeneity and Functional Form Analysis. *Transportation Research Record: Journal of the Transportation Research Board*, 2672, pp. 9-20. DOI: 10.1177/0361198118767409.
23. Watson, D. C., Al-Kaisy, A., Anderson, N. D. (2014). Examining the Effect of Speed, Roadside Features, and Roadway Geometry on Crash Experience Along a Rural Corridor. *Journal of Modern Transportation*, 22, pp. 84-95. DOI: 10.1007/s40534-014-0040-4.

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Modified model of lane capacity at signalised intersections with waiting areas

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Abstract

Left-turn conflicts impact considerably the security and capacity of intersections. There are many practices to decrease conflicts and improve the efficiency of intersections, such as continuous flow intersection (CFI), contraflow left-turn lane, U-turn etc., however, the method of installing waiting areas (WAs) is common in China and it is easier to be accepted by Chinese drivers. Many studies have shown either theoretically or via simulation that WAs improve the traffic capacity greatly. However, few have considered how the vehicle start-up process and red clearance interval differ for lanes with and without WAs. Comparing the start-up lost time of intersections with and without WAs, This work explores the difference of clearance interval between intersections with and without WAs by conflict method, then establishes a modified capacity model about lanes with WAs. Finally, through field investigation of an intersection with left-turn WAs in Zhengzhou, the parameters needed for the modified model are determined. It is shown that the capacity of a lane with a 29-m WA and 18-s green time is increased by only 8.9%.

Keywords – signalised intersection, waiting area, capacity, model

1. Introduction

Intersections act as bottlenecks for urban traffic, leading readily to traffic conflict and congestion. Conventional optimization methods come in two types, one being to optimize the schedule to give the traffic flows in different directions more-reasonable right of way; intersection signal control strategies and theories have been studied considerably since the 1940s. The other approach is to reduce conflicts and improve traffic capacity by optimizing intersection space. In practice, the two methods usually need to be combined.

Turning conflicts, especially left-turn conflicts (right-hand driving), impact greatly the security and capacity of intersections. To reduce left-turn conflicts, common practice is to use a design involving a protected left-turn phase. However, when such a phase is used, only vehicles that are turning left can pass through the intersection during this period, thereby reducing the utilization rate of the intersection. Also, time is lost to start-up and clearance in each phase, thereby adding to the total lost time of the signal cycle and reducing the efficiency and capacity of the intersection. Increasingly, Chinese cities are installing waiting areas (WAs) to improve the operating efficiency of their signalised intersections, with left-turn WAs (LWAs) being the most common.

In recent 10 years, traffic congestion has increased and spread to medium-sized and small cities in China, and more methods for improving traffic efficiency are being applied in practice, such as installing LWAs and through-movement WAs (TWAs). Yang et al.[1-2] used the regression method to analyse the start-up lost time with an LWA and established a delay model. Ma et al. [6] studied the conditions of installing LWAs and then discussed how to optimise the effect of WAs. Yang et al. [7] and You [8] established an evaluation system and a model for TWA; by supplying the model with data, the results of You [8] showed that delays could be reduced by 5.6%.

Gao et al. [3] and Liu et al. [19] used simulation methods to prove that both LWAs and TWAs can reduce delays and improve lane traffic capacity. Yang [1-2] established a lane capacity model for LWAs and calculated that LWAs could improve traffic capacity. In the case of Yang [1], a LWA with a storage capacity of 3 vehicles can increase the traffic capacity by 30.3% under the condition of 15 s green time. However, Yang [1-2] did not consider the start-up process and clear-up process when establishing the capacity model, which would exaggerate the effect of WA. Chen et al. [4] and Chen et al. [5] respectively established capacity models considering the start-up process. Chen et al. [4] used the theory of traffic waves to establish a departure-process model for a left-turn lane with a WA. By analysing the start-up regularity of queuing vehicles, Chen et al. [5] established acceleration and speed models with the regression method and modelled the capacity of a left-turn lane with a WA; in the quoted case, the capacity was increased by 10–20%. Although the start-up process is considered by Chen et al. [4] and Chen et al. [5], the influence of installing WAs on site clear-up process has not been analysed.

Although the installation of WAs can improve the efficiency of intersections, this practice may lead to other traffic problems. Xia et al. [9] used simulation technology to show that comprehensive WAs are more suitable for high traffic volumes and actually worsen the traffic operation for low traffic volumes. Gao et al. [3] used the stop-line method to model the WA length, and simulation results showed that an LWA reduces the queue length but increase the stops. Hao and Yang [10] proposed a method of setting a pre-signal before the left-turn phase to eliminate the extra stops caused by setting WAs. Jiang et al. [11, 20] used the traffic conflict technique and the ordered probit model to show that an LWA reduces the degree of conflict and increases safety; however, upon setting a TWA, drivers' illegal behaviours, such as changing lanes in violation of regulations, will lead to the negative result.

Although there are many practices to improve the efficiency of intersections, such as continuous flow intersection [21,22], contraflow left-turn lane [23,24], displaced left-turn, integrated WA[25], integrated WA[26], controllable shared lane design[27], etc., the method of installing WAs is more common in China and it is easier to be accepted by Chinese drivers. In summary, the previous studies [1-10] have proved that installing WAs can improve the operation efficiency of intersections. However, no study has been conducted so far to take into account the differences in the start-up process between vehicles in lanes with and without WAs, nor did the changes in clearance time caused by the changes in entrance time as such. The two processes of intersections with or without WAs are obviously different. When a signal turns green, the waiting vehicles do not start immediately, and there is usually driver's reaction time in a lane without a WA. However, in a lane with a WA, the vehicles in the WA start first when the signal turns green. The first vehicle outside the WA does not start moving until the last vehicle in front is observed to move, and consequently it takes more time for the first vehicle outside the WA to start moving. Therefore, the purpose of this study is to accurately assess the impact of WAs on the traffic capacity of intersections. This work includes three main components: (1) comparing the start-up lost time of intersections with and without WAs; (2) exploring the difference of clearance interval between intersections with and without WAs by conflict method; (3) modifying the capacity model of lanes with WAs.