The Correlation Between Education, Engineering, Enforcement, and Self-Reported Seat Belt Use in Tennessee: Incorporating Heterogeneity and Time of Day Effect

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Abstract

Time of day and heterogeneity are two common factors that received less attention in self-reported studies concerning seat belt use. Although nighttime seat belt use rate is relatively lower than daytime, previous studies have often not separated the analysis of seat belt use between daytime and nighttime. To incorporate heterogeneity in our analysis, we used random parameters and geographically weighted regression models to explore the factors influencing seat belt use. This study consists of a self-reported seat belt use survey conducted in a sample of 814 respondents aged 18-50 years in six counties (50 zip codes area) in East Tennessee. Comparison of the models indicated that the geographically weighted model outperformed other models. Considering the non-stationary test, we learned that the local coefficients displayed relatively constant variation across space in the study area, which indicates behaviors, at least across a large metropolitan area, does not vary spatially. For the random parameter models, age and income had random parameter effects. Perception of receiving a ticket for not wearing a seat belt, uncomfortable seat belt design, driving for a short distance, and driving exposure also had significant negative associations with self-reported seat belt use in both models. Moreover, exposure to educational programs had a significant correlation with seat belt use only in nighttime, whereas the correlation was insignificant for daytime. Findings provide new insight for design and convoy new messages to promote seat belt use by targeting factors predicting seat belt use. Results are discussed in line with road safety analysis.

Keywords: Self-reported Seat Belt; Daytime; Nighttime; Geographically Weighted Regression; Random Parameter Model

Introduction

There are approximately 1,000 fatalities on the roads in Tennessee, United States every year. One known solution that reduces the fatality rate of the vehicle occupants is a proper use of seat belts. Several studies have reported the importance of wearing a seat belt in reducing crash fatalities and injury rates. Appropriate use of seat belt increases the chance of vehicle occupants surviving a potentially fatal crash by 44% to 73% depending on seating position and the type of vehicle involved (Blincoe *et al.* 2015). Despite the proven effectiveness of these protective devices, some high-risk populations still neglect using them. National Highway Traffic Administration –NHTSA (2017) reported that on average, Tennesseans have lower seat belt use rates compared to the United States average. Despite a few studies that aim to understand lower seat belt use rate in Southern states and specifically in Tennessee, little is known about potential factors correlating with seat belt use in this area. As a result, it is challenging to deploy effective countermeasures.

Seat belt non-use could be attributed to human factors such as forgetfulness, laziness, perceptions about injury likelihood, discomfort (Begg and Langley 2001); attitudes, beliefs , and individuals' habits (Chliaoutakis *et al.* 2000, Calisir and Lehto 2002, Şimşekoĝlu and Lajunen 2008). Driving context and environment also impact seat belt use. Roadside observations also indicated urban areas or expressways have a higher seat belt compliance rate (Glassbrenner and Ye 2007, Nichols *et al.* 2009, Reagan *et al.* 2013).

A number of studies have also shown that nighttime seat belt use rates are significantly lower compared to daytime rates (Chaudhary *et al.* 2005, Chaudhary and Preusser 2006, Solomon *et al.* 2007, Varghese and Shankar 2007, Vivoda *et al.* 2007, Tison *et al.* 2010). However, most studies to date tended not to stratify the analyses across driving during daytime and nighttime, and the majority of the studies have focused on daytime (Boakye *et al.* 2018). In a study in Tennessee, Boakye *et al.* (2018) reported that vehicle occupants traveling after 10 p.m. are more likely not to use a seat belt. This was also supported by Hezaveh and Cherry (2019), who reported that seat belt use rates are lower during dark hours in Tennessee. Although the vehicle miles traveled during daytime is substantially higher than nighttime, the fatality rate in nighttime is almost three times more than daytime (Varghese and Shankar 2007). Alcohol, speeding, and unrestrained driving are among risk factors that contribute to the higher fatality rates in the nighttime. Consequently, fatally injured vehicle occupants are relatively higher during nighttime compared to the daytime (Varghese and Shankar 2007).

Broadly speaking, different countermeasures could be used to target the source of this aberrant behavior. These countermeasures could be classified into three main categories; education, engineering (i.e., *vehicle engineering*), and enforcement (the 3Es). ***Educational and Enforcement strategies*** are crucial for developing safe behavior. Prior studies showed the effectiveness of ***Enforcement*** and enforcement programs such as Click It or Ticket (CIOT) and saturation patrols (Reinfurt 2004, Solomon *et al.* 2004, Thomas *et al.* 2008, National Highway Traffic Safety Administration 2010, Tison and Williams 2010, Thomas *et al.* 2011); however, the magnitude of their effect is unknown. (Morgan 2015, Thomas III *et al.* 2017). It should be noted that there are a variety of campaigns ongoing in Tennessee and the United States that target seat belt use. Nevertheless, the extent of each campaign, such as the study area, type of message, and the targeted population is not known.

Engineering plays an important role in individuals' tendency to use a seat belt. Cunill *et al.* (2004) indicated that uncomfortable seat belts are among reasons that contribute to lower seat belt use. Forgetting to wear a seat belt is another factor that affects seat belt use (Freedman *et al.* 2007). Vehicle engineering countermeasures such as an ergonomic seat belt design as well as enhanced seat belt reminder systems (ESBRs) contributed to an increase in seat belt use (Freedman *et al.* 2007, Freedman *et al.* 2009). ***Sociodemographic*** factors also influence seat belt use. In general, males (Gkritza and Mannering 2008, Pickrell and Ye 2009, Hezaveh and Cherry 2019) and younger vehicle occupants (Calisir and Lehto 2002, Glassbrenner *et al.* 2004) are more prone to not wearing a seat belt compared to females and older adults. Higher education and income were also associated with higher seat belt use rates (Wells *et al.* 2002, Houston and Richardson 2005). In addition, studies in the United States have further shown that African-Americans are less likely to use a seat belt compared to Whites or Hispanics (Vivoda *et al.* 2004, Gkritza and Mannering 2008, Pickrell and Ye 2009).

Studies that used self-reported instruments to investigate factors influencing seat belt use mainly used the Health Belief Model or Theory of Planned Behavior (e.g., Şimşekoğlu and Lajunen 2008, Ali *et al.* 2011, Brijs *et al.* 2011). Although these theories provide valuable information about factors influencing seat belt use, they do not provide information about the role of perceived enforcement, exposure to educational programs, or engineering factors. Likewise, questionnaire-based studies in the United States did not consider the role of time of day.

Heterogeneity

Analyzing heterogeneity has received less attention in self-reported studies concerning the use of safety equipment. Unobserved heterogeneity has been reported in several road safety analyses and transportation studies (e.g., Mannering *et al.* 2016, Yang *et al.* 2017). Unobserved heterogeneity could be attributed to factors that are not likely to be available for analysis (Mannering *et al.* 2016). This phenomenon impacts the relationship between exogenous variables and dependent variables; therefore, this relationship may not be constant across all observations. Failing to address unobserved heterogeneity in the modeling process would lead to biased estimation and incorrect inferences (Mannering *et al.* 2016).

There are two major approaches for addressing heterogeneity in the analysis. The aspatial approach enables the coefficients to vary across the population. Random parameters (RP) models allow the parameters to vary across observations according to a predefined distribution (Washington *et al.* 2010). One of the shortcomings of the random parameter model is that it usually fails to consider the location of observations. The second approach considers the presence of spatial heterogeneity or spatial non-stationarity. Spatial heterogeneity exists when exogenous variables do not vary identically across space (Xu *et al.* 2017). Spatial models such as geographically weighted regression (GWR) consider the location of the observations to capture spatially structured variability in the effect of contributing factors (Xu and Huang 2015). Several studies in other domains in road safety showed the advantage of GWR models with regards to improvement in model goodness of fit and their capability to explore the spatially varying association among dependent variables and exogenous variables (e.g., Pirdavani *et al.* 2014, Xu and Huang 2015).

Considering the current gaps in the road safety literature, this study has several aims. First, to develop a questionnaire that considers the role of education, engineering, and enforcement as well as sociodemographic variables on seat belt use. Second, to consider the effect of time of day by utilizing separate questions that consider self-reported behavior for daytime and nighttime. Third, to consider the effect of heterogeneity in the modeling process. Given the diversity in land use, transportation systems, demographics, and culture; we hypothesize that estimated coefficients of exogenous variables vary across individuals as well as across study areas in the Knoxville region. The results of this study may enable researchers to develop and implement properly targeted educational and enforcement countermeasures to increase seat belt use in Tennessee.

Methods

Participants

Data for this study were collected by the Center for Transportation Research at the University of Tennessee, through the University's social science research institute. The survey was conducted in August 2017. A mixed-mode phone-survey was conducted in East Tennessee. The region includes a mix of urban, suburban, and rural populations that are distributed along corridors and radiate from the Knoxville urban core. The phone survey targeted residents aged between 18-50 years in these regions. The respondents were selected by using a random stratified sample of cell phone and landline telephones from a database of listed phone numbers where the demographics of household members are either known or modeled based upon characteristics of the surrounding neighborhood. The response rates for landline phones and cell phones were 9.8% and 8.4% respectively, which was within the range of response rates achieved in other telephone surveys in the United States (Keeter *et al.* 2017).

Questionnaire

The self-reported questionnaire consisted of five sections. Table 1 presents the list of items and respective response anchors. Demographics section included items about participants' age, gender, residential area (county, city, zip code), number of children in the household, ethnicity, educational degrees, and marital status. Driving habit section included items regarding participants' exposure to driving in nighttime and daytime (separate questions for the time of the day), driving license possession, and whether they had driven a vehicle in the past 30 days preceding the interview. Individuals' history of crashes (i.e., whether they had been involved in a traffic crash) and whether they thought seat belt use could affect the injury outcome (i.e., positive impact, no impact, negative impact on injury outcome) was also recorded with these questions.

The exposure to educational campaigns section included items about respondents' exposure to police and educational activities for promoting seat belt use. Respondents were also asked whether they could recall or had heard about or read any message or slogan that was used in the police and educational activities regarding seat belt use for both daytime and nighttime. In addition, the respondents reported their perceived probability of receiving a ticket for not wearing a seat belt. Respondents answered questions in this section both for nighttime and daytime.

Table 1 Items and response categories related to education, engineering, and enforcement

Content	Item Description	Response categories
Education		
	In the past30 days have you seen or heard any messages that encourage people to wear their seat belts?	Yes/no
	In the past 30 days have you seen or heard an ad or slogan about wearing a seat belt at nighttime?	Yes/no
	Recall seat belt use message or slogans for daytime?	Yes/no
	Recall seat belt use message or slogans for Nighttime?	Yes/no
Attitude		
	Do you think it is more important to wear a seat belt while driving during the day or is it more important to wear a seat belt while driving after dark?	More important during the day More important after dark No difference Not sure
	How acceptable do you think it is for a driver not to wear a seat belt during daylight hours?	Completely unacceptable Somewhat unacceptable Neither Somewhat acceptable Completely acceptable
	How acceptable do you think it is for a driver not to wear a seat belt during nighttime hours?	Completely unacceptable Somewhat unacceptable Neither Somewhat acceptable Completely acceptable
Enforcement		
	In the past 30 days have you seen or heard anything about seat belt law enforcement by the police?	Yes/no
	Assume that you do not wear your seat belt at all over the next Six months. How likely do you think you will be to receive a ticket for not wearing a seat belt?	Very likely Somewhat likely Somewhat unlikely Very unlikely Don't know
	The effectiveness of An increase in the cost of insurance for those who do not wear a seat belt?	1. Not at all effective 2. Somewhat effective 3. Very effective
	The effectiveness of Receiving negative points on their driver's license?	Yes/no
	The effectiveness of Increase in insurance premium?	Yes/no
Vehicle Engineering		
	The seat belt is uncomfortable*	Yes/no
	I forgot to put it on*	Yes/no
Other reason		
	I'm only riding a short distance*	Yes/no
	I get in and out of my vehicle frequently*	Yes/no
	I don't like being told I have to wear a seat belt*	Yes/no

* separate questions for daytime and nighttime

In the engineering section, respondents were asked whether their seat belt comfort and forgetfulness were reasons for not wearing a seat belt. Issues regarding seat belt design and seat belt reminders are addressed with vehicle engineering design. In the seat belt use habits section, we asked respondents how often they wear their seat belt when they are seated in the driver seat during nighttime. The questionnaire also included three questions regarding individuals' attitude toward wearing a seat belt in nighttime and daytime. In addition, respondents were asked whether the driving length and frequently getting in and out of the vehicle were reasons for their seat belt non-use.

Logit Model

Fixed and Random Parameter models

A Fixed-Parameter (FP) binary logit model was used to investigate the correlation between covariates and self-reported seat belt use. Equation 1 describes the closed-form solution of the binary logit model (Washington *et al.* 2010):

$$p(Y_i = always) = \frac{\exp\,(\alpha_i + \beta X_{ij})}{1 + \exp\,(\alpha_i + \beta X_{ij})} \qquad \text{Equation 1}$$

where β is the vector of estimated parameters and X_{ij} is the vector of variables explaining data elements in the questionnaire. The linear form of the binary logit model is also presented below (Liu and Khattak 2017):

$$Logit\,(P|Y_i = always) = \alpha_i + \beta_i X_i \qquad \text{Equation 2}$$

Random-Parameter model (RP) considers the effect of unobserved heterogeneity by enabling the estimated coefficient to vary across individuals (Washington *et al.* 2010):

$$p(Y_i = always) = \frac{\exp\,(\alpha_i + \beta_i X_{ij})}{1 + \exp\,(\alpha_i + \beta_i X_{ij})} \qquad \text{Equation 3}$$

This heterogeneity among drivers is assumed to follow one of several parametric distributions (e.g., normal, lognormal, triangular, etc.) and is reflective of those unobserved factors that may influence respondents' choice to wear a seat belt. This random constant term essentially partitions the variance into two components: a normally distributed error term with zero mean, which varies across respondents; and the generalized extreme value error term described previously. Since the resulting model formulation does not have a closed-form solution, simulated maximum likelihood methods are used to estimate the random parameters model shown in Equation (4) (McFadden 1981):

$$p(Y_i = always) = \int_x \frac{\exp\left(\alpha_i + \beta_i X_{ij}\right)}{1 + \exp\left(\alpha_i + \beta_i X_{ij}\right)} f(\beta|\phi) d\beta \qquad \text{Equation 4}$$

where $f(\beta|\phi)$ is the density function of β with ϕ referring to a vector of parameters of the density function (mean and variance), and all other terms as previously defined. By using this approach, logit probabilities are approximated by drawing values of β_i from $f(\beta|\phi)$ for given values of ϕ. We used 500 Halton draws as part of model estimation as an alternative to random draws. Previous research has demonstrated the effectiveness of this method (Halton 1960, Savolainen 2016). Moreover, we assumed a normal distribution functional form for the parameter density functions. For more details about the random parameter and its estimation, please see Greene and Hensher (2003).

Geographically Weighted Regression model

A GWR model allows the estimated coefficients to vary based on the coordinates of the observations. Consequently, each observation has its own coefficients. Equations 5 and 6 present the global and local form of a linear regression model (Fotheringham *et al.* 1998).

$$Y = \alpha + \beta X \qquad \text{Equation 5}$$

$$Y_i = \alpha(u_i\ v_i) + \beta(u_i\ v_i)X \qquad \text{Equation 6}$$

where X is a vector of covariates, $\beta(u_i\ v_i)$ is the local coefficient for the i^{th} observation at the location corresponding to $(u_i\ v_i)$ coordinates; $\alpha(u_i\ v_i)$ also presents the constant term for the i^{th}. Self-reported zip code was also used to extract the coordinates of each observation.

The local GWR models are estimated based on specific kernel functions. Gaussian and bi-square (fixed or adaptive) are two common types of kernel functions for estimating a GWR model. The main difference between Gaussian and bi-square kernel functions are the effect of observations outside of the bandwidth limit. The bi-square kernel nullifies the effect of observations outside of the predefined bandwidth (a weight of zero), whereas the Gaussian kernel considers their effect (Bidanset and Lombard 2014). The bandwidth size also could be calculated based on a fixed or adaptive approach. Unlike the fixed approach that uses a fixed distance to determine the weight matrix, the adaptive kernels consider a variable-bandwidth based on the location of each observation and their proximity to other observations. Therefore, the adaptive approach considers the inhomogeneous distribution of the sample across space. For more information about the weighting matrix, please see Nakaya (2014).

To determine a proper kernel in the GWR model, we used Fixed Gaussian, Fixed bi-square, adaptive bi-square, and adaptive Gaussian kernels. We also used corrected Akaike Information Criteria (AICc) to determine the best-fitted kernel (Hurvich *et al.* 1998). AICc is a function of Akaike Information Criteria (AIC), which is adjusted for the number of parameters (k) and sample size (n) ($AICc = AIC + \frac{2k^2+2k}{n-k-1}$) (Hurvich *et al.* 1998). The model with the lowest value of AICc is statistically superior to other models (Fotheringham *et al.* 2003, Hadayeghi *et al.* 2010).

We also calculate the average marginal effects (AME) for each variable, the marginal effect measures the change in the expected value of seat belt use as one independent variable increases by unity while all other variables are kept constant (Bartus 2005). AME is also the average of the marginal effect of all the observations. For more details regarding the calculation of the AME see Bartus (2005).

Non-Stationary Test

The estimated local coefficients in the GWR model may display relatively constant variation across space, and therefore, we can interpret them as approximately equal to the stationary coefficients of global models. The non-stationarity test is one method to test for the presence of coefficient variation over space by considering the differences between the upper and lower quartile of the estimated coefficients (δ) from the GWR model (Liu and Khattak 2017). If the GWR model does not meet the condition in equation 7, the spatial variations are unsubstantial, and the coefficient is considered as the global coefficient.

$$\begin{cases} \delta > 1.96 * SE \; and, & \\ 1.96 < \max(|z_i|) & Pass \; the \; test \; (local \; coefficient) \\ if \; not & failed \; to \; pass \; (global \; coefficient) \end{cases} \qquad \text{Equation 7}$$

In Equation 7, SE is the standard error of the coefficient in the global binary logit model, and (z_i) is the significance z-score of the GWR model for observation i, which can be calculated as $\left|\frac{\beta(u_i,v_i)}{SE(u_i,v_i)}\right|$. For further details regarding the GWR calibration, please see Nakaya *et al.* (2005). In order to estimate the binary GWR model, the GWR4.0 software was used (Nakaya *et al.* 2012).

Model Comparison

To investigate the relative statistical performance of the random parameter and global model, we used the likelihood ratio tests. The test statistic is computed as reported in Washington *et al.* (2010):

$$\chi^2 = -2[LL(\beta_{RP}) - LL(\beta_{GM})] \qquad \text{Equation 8}$$

where, $LL(\beta_{RP})$ and $LL(\beta_{GM})$ are respectively, the log-likelihood function at the convergence of the random parameter and global models. The test statistic follows a chi-squared distribution with degrees of freedom equal to the difference in the number of random parameters in the RP models. In order to compare the goodness of fit of the spatial model and aspatial models, we compared AICc values.

In the GWPR, due to the non-parametric framework of the model, there is a need to use the effective number of parameters instead of the actual number of parameters in the model. For more details on the calculation of the effective number of parameters, please see Nakaya *et al.* (2005). Furthermore, Variance Inflation Factors (VIF) was used to control for multicollinearity. As a rule of thumb, a VIF value greater than 10 is an indicator of the high level of multicollinearity (see O'Brien, 2007 for details).

Results

The sample included 814 respondents (358 males and 456 females). Respondents reported 50 distinct zip codes at the time of their interview. The average number of respondents from each zip code was 16.3 (SD = 11.7, range: 1-42). Figure 1 presents the spatial distribution of the respondents. Urban areas (i.e., the center of Figure 1) had a higher number of respondents compared to the rural area. Respondents average age was 34.2 years (SD = 9.0, range 18-50 years). Table 2 also presents the education degrees among the respondents; more than 40% of the respondents had bachelor's degree or graduate degree. Moreover, 94% of the respondents reported White as their ethnic group.

In general, respondents were more likely to drive during the daytime (Table 3). The seat belt use rate during daytime was also slightly higher than during the nighttime. On average, 89.0% and 89.2% of the respondents stated that they always wear their seat belts during nighttime and daytime, respectively (see Table 3 for more details).

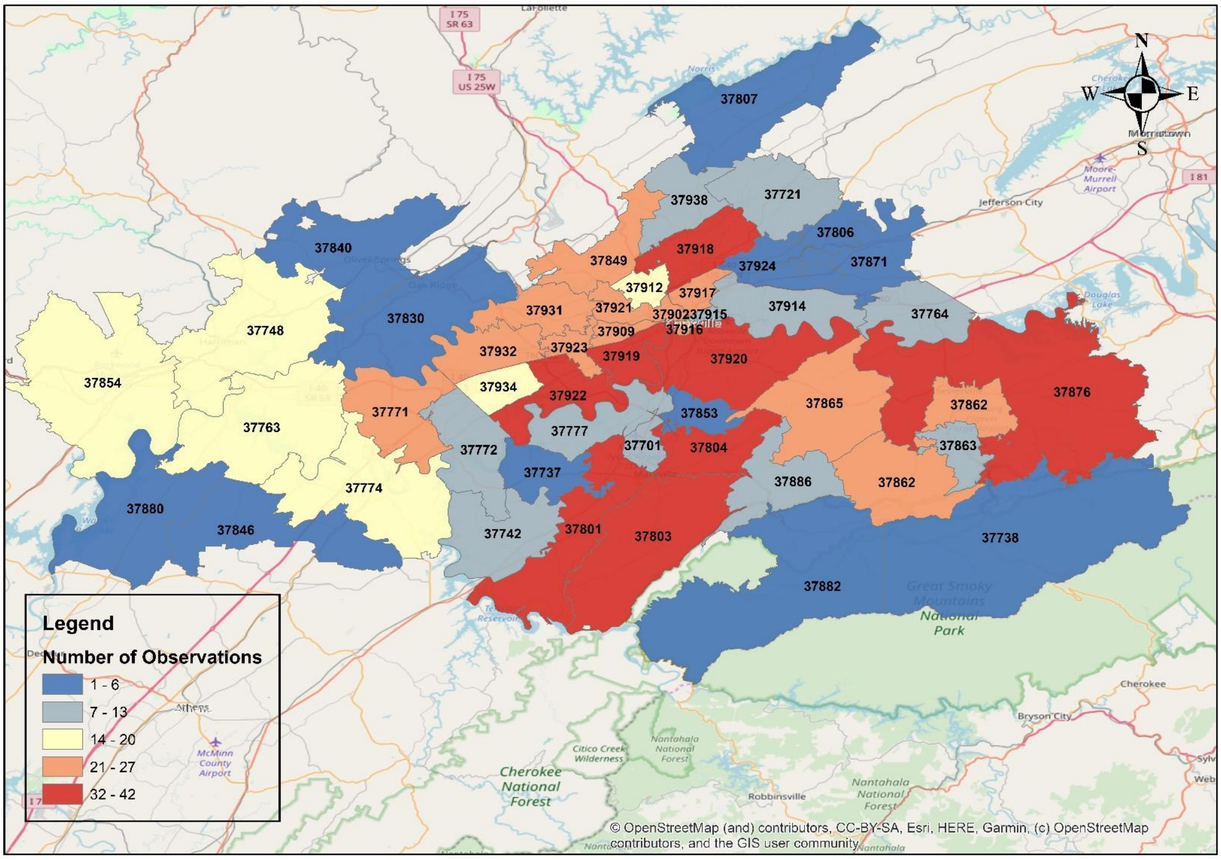

Figure 1 Study area and number of observations

Table 2 Respondents' education distribution

Education Degree	Frequency (%)
High school graduate or General Educational Development or less	162 (20.1%)
Some college degree	307 (37.7%)
Bachelor's degree	226 (28%)
Graduate or professional degree	116 (14.4%)

Table 3 Driving and seat belt use habit

	Nighttime	Daytime
Driving Habit		
Few times a month	104 (13.5%)	19 (2.4%)
A few times a week	263 (34.2%)	55 (7%)
Almost every night/day	178 (23.2%)	164 (20.9%)
Every night/day	224 (29.1%)	546 (69.6%)
Seat belt use		
Always	724 (89%)	726 (89.2%)
Almost always	44 (5.5%)	42 (5.2%)
Sometimes	13 (1.7%)	17 (2.2%)
Rarely	12 (1.5%)	9 (1.2%)

Almost 43.6% of the respondents remembered the slogan that was used in an educational campaign. Respectively, 35.7% and 6.6% of all the respondents were able to recall slogans that were used for encouraging daytime and nighttime seat belt use (e.g., Governor Haslam's just buckle up, click it or ticket, click it or ticket day or night, buckle up –it's the law). Majority of the above-mentioned slogans promote the use of seat belt by focusing on seat belt laws and the penalty (i.e., a ticket) for not wearing a seat belt. Notably, 67.0% of the respondents reported having seen a message regarding a seat belt campaign that encourages people to wear a seat belt in the past 30 days (by the time of the interview). This number for encouraging seat belt use at nighttime was 19.1%. Likewise, 25.0% of the respondents reported having heard or seen a message regarding law enforcement to encourage individuals to wear a seat belt in the past 30 days.

Survey results also indicated that respectively 20.7% and 22.4% of the respondents stated that it is very unlikely and somehow unlikely to receive a traffic ticket if they do not wear a seat belt in the next six months. In response to the effectiveness of the negative point to a driver license or increased insurance premium for not wearing a seat belt, 47.8% and 53.9% of the respondents indicated that these countermeasures are very effective (Table 4). Also, 93% of the respondents reported that there was no difference between the importance of seat belt use in daytime and nighttime.

Table 5 presents respondents' concerns about engineering factors and reasons for not wearing a seat belt. Among reasons for not wearing a seat belt, driving for a short distance was the most frequently reported reason for not wearing a seat belt for both daytime and nighttime. Forgetting to wear a seat belt was also the second most reported reason for not wearing a seat belt.

Additionally, 53.3% of the respondents had experienced a severe traffic crash-related injury among their friends or family members, and 16.0% reported being seriously injured in traffic crashes. Out of those who were involved in traffic crashes, 24.6% reported a positive impact of the seat belt in crash outcome by preventing fatal crashes. On the other hand, 10.0% of the respondents believed that seat belt use could worsen the injury outcome, and 65.4% reported that seat belt use had no impact on injury outcome.

Table 4 Respondents' answers on questions regarding attitude and enforcement

Content	Question Description	Response	%
Attitude	Do you think it is more important to wear a seat belt while driving during the day or is it more important to wear a seat belt while driving after dark?	More important during the day	4.1
		More important after dark	3.0
		No difference	93.0
	How acceptable do you think it is for a driver not to wear a seat belt during daylight hours?	Completely unacceptable	5
		Somewhat unacceptable	4.1
		Neither	5.5
		Somewhat acceptable	11.2
		Completely acceptable	74.3
	How acceptable do you think it is for a driver not to wear a seat belt during nighttime hours?	Completely unacceptable	5.3
		Somewhat unacceptable	3.9
		Neither	5.1
		Somewhat acceptable	10.3
		Completely acceptable	75.4
Enforcement	In the past 30 days have you seen or heard anything about seat belt law enforcement by the police?	Yes	25.0
		No	75.0
	Assume that you do not wear your seat belt at all over the next Six months. How likely do you think you will be to receive a ticket for not wearing a seat belt?	Very likely	20.9
		Somewhat likely	22.0
		Somewhat unlikely	30.9
		Very unlikely	26.2
		Don't know	
	The effectiveness of an increase in the cost of insurance for those who do not wear a seat belt?	Not at all effective	14.3
		Somewhat effective	31.8
		Very effective	53.9
	The effectiveness of receiving points on their driver's license?	Not at all effective	11.3
		Somewhat effective	40.5
		Very effective	47.8

Table 5 Respondents' answers on questions regarding engineering and reasons for not wearing a seat belt

Content	Question Description	Response	Daytime %	Nighttime %
Engineering	The seat belt is uncomfortable*	Yes	5.6	5.6
		No, and other	94.4	94.3
	I forgot to put it on*	Yes	7.0	6.0
		No, and other	93.0	94.0
Reasons for seat belt non-use	I'm only riding a short distance*	Yes	16.3	13.3
		No, and other	83.7	86.7
	I get in and out of my vehicle frequently*	Yes	6.3	4.3
		No, and other	93.7	95.7
	I don't like being told I have to wear a seat belt*	Yes	5.4	5.5
		No, and other	94.6	94.5

Analysis of variance (ANOVA) shows that the effect of education on seat belt use in daytime was insignificant, (F (4, 789) = 1.49, p = 0.21); in contrast, education had a significant effect on nighttime seat belt use (F (6, 787) = 3.14, p = 0.025). Female drivers (daytime mean = 0.91; nighttime mean = 0.92) had higher seat belt use rate in comparison to males (daytime mean = 0.87; nighttime mean = 0.87) regardless of time of day (daytime: t (812) = 2.01, p = 0.045; nighttime: t (812) = 2.12, p = 0.034). Furthermore, those who drive more during nighttime had lower seat belt use rate (F (3, 765) = 3.17, p = 0.02). Driving exposure did not have any effect on self-reported seat belt use for daytime (F (3, 783) = 1.39, p = 0.25). Income level also did not have a significant effect on self-reported seat belt use (Daytime: F (6, 807) = 1.53, p = 0.16; Nighttime: F (6, 807) = 1.07, p = 0.38).

Model Comparison

Table 6 presents the goodness of fit of estimated models based on AICc. In both models (i.e., daytime and nighttime), the GWR model outperformed both the FP model and RP models (lower AICc). Moreover, the estimated RP models fit significantly better than the FP models (Daytime $\chi^2(2) = 6.7$; Nighttime $\chi^2(2) = 6.4$). We also found that age (36-50 years) and income variables had a significant random parameter effect (with positive mean) in both daytime and nighttime models.

Table 7 and Table 8 present the results of estimated FM, RP, and GWR models as well as the average marginal effect of each variable. The average VIF value for the daytime model and nighttime model was respectively 1.31 (range 1.03-1.94) and 1.27 (range 1.03-1.96).

It should be noted that the adaptive bi-square model had a better fit compared to other kernel types in both daytime and nighttime models. To maintain concision, we only present the result of the adaptive bi-square kernel. Results of the non-stationary test indicate that the existence of coefficient variation over the space was not substantial in the estimated models. Therefore, we can conclude that the estimated variables have global effects. We speculate that the lack of substantial spatial variation across space is due to the limited study area size that only covers one metropolitan area with a population of one million that may share similar traffic culture. Nevertheless, this is an important null result and provides some evidence that behaviors, at least across a large area (i.e., East Tennessee), do not vary spatially.

Parameter estimation

The significant predictors of seat belt use are presented in bold font in Tables 7-8. Overall, the designed framework for self-reported seat belt use for daytime and nighttime have similar performance (apart from exposure to message and ad regarding nighttime seat belt use in the past 30 days). Furthermore, comparison of the estimated coefficients in Tables 7 and 8 indicates that the sign of estimated coefficients for all three models is consistent. The value of estimated coefficients for random parameter and global models lie within the range of the corresponding coefficients in the GWR model.

Analysis of the local distribution of the estimated coefficients in the GWR models indicates that some of the variables (e.g., gender, White ethnicity, age group; education degree, household size, income) the sign of local estimated coefficients varies from negative to positive, which is some cases are not consistent with the RP and FM models. However, controlling for the significance level of the local coefficients, we learned that local coefficients with unexpected values are insignificant.

Table 6 Measures of model goodness of fit

	Daytime			Nighttime		
	GM	**RP**	**GWR**	**GM**	**RP**	**GWR**
Log Likelihood	-179.5	-176.1	-159.4	-163.7	-160.6	-150.1
AIC	413.0	410.3	405.5	385.5	381.1	375.2
AICc	415.0	414.9	410.7	387.6	383.6	380.7
K (number of parameter)	27	29	43.4	28	30	37.53
n (number of obs.)	790	790	790	788	788	788
Chi-square test						
$\chi^2 = -2[\text{LL}(\beta\text{random}) - \text{LL}(\beta\text{fixed})]$						Critical Value
RP vs GM	6.7**	(2, 5.99) †		6.4**	(2, 5.99) †	
Changes in AICc						
GWR vs. GM (AICc)	20.1			13.7		
GWR vs. RP (AICc)	16.8			10.5		

**Significant at 0.05 level
† (degree of freedom, critical value)

Table 7 Estimated models for daytime seat belt use

	Fixed-Parameter			Random Parameter			GWR	
	Coefficient	SE	P-value	Coefficient	SE	P-value	(Min, Q1, Median, Q3, Max)	AME†
Constant	-2.002	1.307	0.126	-1.783	1.21078	0.141	(-2.94, -2.77, -2.54, -2.36, -1.85)	
In the past 30 days have you seen or heard any messages that encourage people to wear their seat belts?	0.114	0.357	0.748	0.024	0.325	0.940	(-0.06, 0.01, 0.06, 0.11, 0.17)	0.006
In the past 30 days have you seen or heard anything about seat belt law enforcement by the police?	0.214	0.366	0.557	0.388	0.333	0.244	(0.06, 0.29, 0.31, 0.34, 0.48)	0.010
How likely do you think you will be to receive a ticket for not wearing a seat belt in the next 6 months?	0.262*	0.134	0.051	0.157	0.124	0.205	(0.15, 0.17, 0.21, 0.22, 0.4)	0.013**
Recall seat belt use message or slogans for daytime?	0.38	0.373	0.309	0.409	0.342	0.232	(0.13, 0.27, 0.38, 0.49, 0.64)	0.019
I'm only riding a short distance‡	-0.806**	0.352	0.022	-0.789***	0.284	0.006	(-1.27, -1.16, -1, -0.9, -0.56)	-0.040*
I forgot to put it on‡	-1.438***	0.430	0.001	-1.509***	0.349	0.000	(-2.03, -1.74, -1.69, -1.6, -1.37)	-0.070**
The seat belt is uncomfortable‡	-1.069**	0.478	0.025	-1.088***	0.368	0.003	(-1.57, -1.22, -0.95, -0.67, -0.52)	-0.052*
I get in and out of my vehicle frequently‡	-0.099	0.490	0.840	-0.14	0.364	0.698	(-0.36, 0.35, 0.35, 0.47, 0.59)	-0.005
I don't like being told I have to wear a seat belt	-0.3	0.463	0.517	-0.388	0.380	0.306	(-0.35, -0.05, 0.08, 0.22, 0.52)	-0.015
Driving during Daytime	-0.432**	0.219	0.049	-0.448**	0.192	0.019	(-0.54, -0.36, -0.3, -0.26, -0.07)	-0.021*
Driving License (1: yes, 0: otherwise)	1.633***	0.549	0.003	1.409***	0.541	0.009	(0.93, 1.3, 1.43, 1.57, 2.11)	0.080***
Positive impact of seat belt in crash outcome	0.572	0.559	0.306	0.824	0.646	0.202	(0.26, 0.6, 0.66, 0.73, 0.93)	0.028
Negative impact of seat belt in crash outcome	-0.155	0.620	0.803	-0.225	0.507	0.657	(-0.46, 0.08, 0.27, 0.49, 1.1)	-0.008
Gender (1: Male, 0: otherwise)	-0.338	0.305	0.268	-0.404	0.270	0.134	(-0.57, -0.3, -0.19, -0.06, 0.03)	-0.017
How acceptable do you think it is for a driver not to wear a seat belt during daylight?	0.607***	0.111	0.000	0.608***	0.114	0.000	(0.63, 0.67, 0.7, 0.74, 0.77)	0.030***
White ethnicity (1 = white, 0 = otherwise)	0.024	0.482	0.960	-0.067	0.399	0.866	(-0.14, -0.03, 0.03, 0.12, 0.22)	0.001
The effectiveness of an increase in the cost of insurance for those who do not wear a seat belt?	0.325	0.373	0.383	0.321	0.338	0.342	(0.12, 0.19, 0.3, 0.39, 0.55)	0.016
The effectiveness of receiving points on their driver's license?	0.69**	0.335	0.039	0.64**	0.283	0.024	(0.36, 0.59, 0.74, 0.9, 1.04)	0.034**
Education (Base: High school or less)								
Some college degree	-0.065	0.377	0.861	-0.029	0.360	0.934	(-0.87, -0.36, -0.14, 0.13, 0.52)	-0.003
Bachelor's degree	0.114	0.442	0.796	0.037	0.409	0.927	(-0.7, 0.08, 0.32, 0.65, 0.75)	0.006
Graduate degree	-0.005	0.556	0.992	0.126	0.509	0.804	(-0.68, -0.17, 0, 0.23, 0.35)	0.000
Household size (Base 3 or more)								
Single	0.112	0.460	0.808	0.067	0.407	0.869	(-0.08, -0.03, 0.05, 0.09, 0.28)	0.005
two persons	0.146	0.347	0.672	0.079	0.311	0.799	(-0.15, -0.03, 0.14, 0.27, 0.53)	0.007
Age group (Base 18-25)								
Age 26-35	0.154	0.403	0.702	0.047	0.361	0.896	(-0.25, -0.07, -0.02, 0.03, 0.28)	0.005
Age 36-50	0.107	0.380	0.778	0.89**	0.375	0.018	(-0.49, -0.14, -0.07, 0.04, 0.27)	0.008
Income	0.01**	0.005	0.034	0.017***	0.005	0.001	(0.011, 0.006, 0.01, 0.01, 0.003)	0.05***
Scale parameters for dists. of random parameters								
Income				0.021***	0.004	0.000		
Age 36-50				2.397***	0.376	0.000		

† Based on the GWR model
‡ Specific question for daytime
× Random parameters
*p < .10; **p < .05; ***p<.01.
Optimal bandwidth = 766

Table 8 Estimated models for nighttime Seat belt use

	Fixed-Parameter			Random Parameter			GWR	
	Coeff.	SE	P-value	Coeff.	SE	P-value	(Min, Q1, Median, Q3, Max)	AME†
Constant	-3.423***	1.139	0.003	-2.962***	0.964	0.002	(-4.45, -3.86, -3.46, -2.91, -2.04)	
In the past 30 days have you seen or heard any messages that encourage people to wear their seat belts?	0.368	0.339	0.277	0.252	0.292	0.388	(0.04, 0.09, 0.16, 0.25, 0.4)	0.015
In the past 30 days have you seen or heard an ad or slogan about wearing a seat belt at nighttime?	**0.863***	**0.472**	**0.067**	**0.88****	**0.396**	**0.026**	**(0.55, 0.79, 1.06, 1.23, 1.48)**	**0.035***
In the past 30 days have you seen or heard anything about seat belt law enforcement by the police?	0.13	0.388	0.737	0.081	0.343	0.813	(-0.07, 0.36, 0.38, 0.41, 0.49)	0.005
How likely do you think you will be to receive a ticket for not wearing a seat belt in the next 6 months?	**0.342****	**0.143**	**0.017**	**0.246****	**0.125**	**0.048**	**(0.22, 0.26, 0.28, 0.32, 0.47)**	**0.014****
I'm only riding a short distance‡	**-0.899****	**0.370**	**0.015**	**-0.871*****	**0.282**	**0.002**	**(-1.55, -1.34, -1.23, -1, -0.47)**	**-0.036****
I forgot to put it on‡	**-1.803*****	**0.472**	**0.000**	**-1.626*****	**0.371**	**0.000**	**(-2.46, -2.33, -2.29, -2.13, -1.63)**	**-0.072*****
The seat belt is uncomfortable‡	**-1.373*****	**0.441**	**0.002**	**-1.265*****	**0.359**	**0.000**	**(-1.62, -1.4, -1.25, -1.15, -0.97)**	**-0.055*****
I get in and out of my vehicle frequently‡	0.138	0.546	0.800	0.243	0.441	0.581	(0.07, 0.29, 0.35, 0.48, 0.67)	0.006
I don't like being told I have to wear a seat belt	-0.306	0.480	0.523	-0.25	0.373	0.502	(-0.33, 0.06, 0.36, 0.51, 0.68)	-0.012
Driving during nighttime	**-0.409****	**0.165**	**0.013**	**-0.37****	**0.159**	**0.020**	**(-0.61, -0.52, -0.47, -0.41, -0.36)**	**-0.016****
Driving License (1: yes, 0: otherwise)	**1.807*****	**0.589**	**0.002**	**1.385****	**0.554**	**0.012**	**(1.03, 1.43, 1.63, 1.83, 2.39)**	**0.073*****
Positive impact of seat belt in crash	0.624	0.587	0.288	0.748	0.665	0.260	(0.1, 0.87, 1.07, 1.17, 1.3)	0.025
Negative impact of seat belt in crash	-0.403	0.603	0.504	-0.63	0.465	0.175	(-0.7, -0.25, 0.06, 0.15, 0.31)	-0.016
Gender (1: Male, 0: otherwise)	-0.206	0.321	0.520	-0.167	0.304	0.580	(-0.63, -0.26, 0, 0.14, 0.24)	-0.008
How acceptable do you think it is for a driver not to wear a seat belt during nighttime?	**0.69*****	**0.113**	**0.000**	**0.618*****	**0.111**	**0.000**	**(0.7, 0.77, 0.82, 0.9, 0.98)**	**0.028*****
White ethnicity (1: white, 0: otherwise)	0.151	0.500	0.762	0.175	0.448	0.696	(0.08, 0.14, 0.17, 0.19, 0.24)	0.006
The effectiveness of an increase in the cost of insurance for those who do not wear a seat belt?	0.34	0.388	0.381	0.355	0.332	0.284	(0.03, 0.14, 0.33, 0.45, 0.63)	0.014
The effectiveness of receiving points on their driver's license?	**0.607***	**0.354**	**0.087**	**0.477***	**0.278**	**0.096**	**(0.26, 0.45, 0.65, 0.73, 0.95)**	**0.024**
Recall seat belt use message or slogans for Nighttime?	-0.091	0.655	0.889	0.006	0.639	0.992	(-0.53, -0.11, 0.09, 0.18, 0.27)	-0.004
Education (Base: High school or less)								
Some college degree	0.246	0.385	0.523	0.252	0.351	0.472	(-0.49, -0.06, 0.12, 0.38, 0.77)	0.010
Bachelor's degree	0.544	0.457	0.234	0.536	0.453	0.236	(-0.21, 0.51, 0.83, 0.98, 1.16)	0.022
Graduate degree	0.723	0.629	0.250	0.839	0.574	0.144	(-0.14, 0.43, 0.85, 1.14, 1.52)	0.029
Household size (Base 3 or more (base)								
Single	0.384	0.514	0.455	0.185	0.409	0.651	(-0.49, -0.06, 0.12, 0.38, 0.77)	0.015
two persons	-0.264	0.352	0.452	-0.323	0.329	0.326	(-0.21, 0.51, 0.83, 0.98, 1.16)	-0.011
Age group (Base 18-25)								
Age 26-35	0.071	0.410	0.861	0.035	0.364	0.922	(-0.31, -0.24, -0.18, -0.05, 0.28)	0.006
Age 36-50	**0.137**	**0.381**	**0.718**	**1.004*****	**0.376**	**0.008**	**(-0.46, -0.13, 0.09, 0.21, 0.44)**	**0.003**
Income	**0.008***	**0.005**	**0.076**	**0.008***	**0.005**	**0.071**	**(-0.14, 0.43, 0.85, 1.14, 1.52)**	**0.020***
Scale parameters for dists. of random parameters								
Income				0.005**	0.003	0.045		
Age 36-50				2.524***	0.392	0.000		

† Based on the GWR model
‡ Specific question for nighttime
× Random parameters
*p < .10; **p < .05; ***p<.01.
Optimal bandwidth = 760

Discussion

Exposure to both educational activities (e.g., advertisements or messages) and police enforcement had no significant effect on seat belt use both in the daytime and nighttime models. Considering the substantial percentage of respondents who were able to remember the slogans (67%), we can conclude that exposure to seat belt materials in the daytime was not as effective as it was intended. Instead, hearing messages or slogans regarding seat belt use at nighttime had a positive impact on self-reported nighttime seat belt use. This was despite the relatively smaller number of respondents who were exposed to nighttime seat belt use materials (19%). Therefore, we can conclude that there is a need to reconsider the educational campaigns materials in the study area to increase their effectiveness in terms of boosting seat belt use.

As the perception of receiving a ticket increased, respondents were more likely to report seat belt use, which indicates the importance of ubiquitous enforcement or at least perception of it in their decision for wearing a seat belt. Previous research has also shown that the enforcement of seat belt laws can greatly increase seat belt use (Hagenzieker 1991, Dee 1998, Eby *et al.* 2000). Unlike increasing insurance premium, receiving a negative point on the driving license had a significant correlation with seat belt use for both daytime and nighttime. This strategy could also be used as an alternative enforcement technique.

Consistent with previous studies (e.g., Freedman *et al.* 2007, Block and Walker 2008, Şimşekoğlu and Lajunen 2008), perceiving seat belts to be uncomfortable contributed to seat belt non-use. A more ergonomic design that targets the source of uncomfortable seat belt use for vehicle occupants has the potential to enhance seat belt use. Despite the presence of ESBRs in most vehicles in the United States, forgetting to put on a seat belt use had a significant correlation with seat belt use; moreover, it was one of the most reported reasons for not wearing a seat belt. Therefore, there is a need to investigate the interaction between vehicle occupants and ESBRs.

In line with previous studies (Şimşekoğlu and Lajunen 2008, Zavareh *et al.* 2018), road users attitudes toward using safety equipment impact their decisions for using the equipment. Riding for a short distance had a significant correlation with seat belt use. Educating vehicle occupants about involvement in serious traffic crashes even in short distance trips has the potential to enhance seat belt use. Alternatively, getting in and out of vehicle frequently and do not like being told to wear a seat belt did not have a significant correlation with seat belt use.

Model estimation indicated that as individuals drive more, their likelihood of wearing a seat belt decreases. This could be attributed to perceived behavioral control, behavioral belief, and comparative optimism (Şimşekoğlu and Lajunen 2008, Zavareh *et al.* 2018). The driving experience could facilitate optimism bias; as a result, drivers may have an illusion of control, in which they overestimate the probability of positive events and underestimate the likelihood of negative events occurring to themselves compared to other drivers (Stephens and Ohtsuka 2014, Zavareh *et al.* 2018).

Unlike previous studies (Gkritza and Mannering 2008, Pickrell and Ye 2009, Hezaveh and Cherry 2019), White ethnicity, male, and education levels did not have a significant correlation with seat belt use. One reason for insignificant correlation could be attributed to the study population that predominantly includes people from the White ethnic group. The age group of 36-50 years had a significant correlation (as a random parameter variable) with seat belt use in both RP models. The significant association could be explained by the power of the RP model to capture the effect of heterogeneity. On the other hand, other age groups did not have a significant correlation with seat belt use in RP and FM models (except the age group of 36-50 years in RP models). Furthermore, those who had a valid driving license or higher income were more likely to report seat belt use. Alternatively, household size did not have a significant correlation with self-reported seat belt use.

Comparison of the significant marginal effect of the coefficients in the daytime and nighttime models indicate that possession of a driving license, forgetting to wear a seat belt, uncomfortable seat belt use design, and driving for a short distance had the highest absolute AME values. On the other hand, the perception of receiving a traffic ticket had the smallest effect on the respondent's decision to wear a seat belt; this is consistent with research showing that risk perception has a weak relation to behavior (Şimşekoğlu *et al.* 2012, Şimşekoğlu *et al.* 2013). Overall, marginal effect analysis implies targeting respondents' excuses through educational materials has greater impact compared to focusing on enforcement aspect of seat belt use.

Conclusion, implications, and limitations

In this study, we explored the effect of both spatial and aspatial heterogeneity in a study of self-reported seat belt use during both daytime and nighttime by using separate questions.

Comparison of the statistical models indicated that the geographically weighted regression models outperformed both random and fixed-parameter models. Findings of this study could be used in different aspects of the design of a seat belt educational program. First, bearing in mind the difference between daytime and nighttime seat belt use, particularly the role of exposure to educational materials, there is a need to consider the nighttime seat belt use in future studies.

Second, lack of substantial variation of the estimated local coefficients in the geographically weighted regression is an important null finding, which could be used in the selection of sample (e.g., for exploring factors predicting seat belt use) in a metropolitan area. As a result, more effort could be dedicated to the sample to be representative of the sociodemographic composition rather than the spatial coverage of a geographic area.

Third, most messages incorporated into the current educational campaigns focus on the law aspect of seat belt use. Nonetheless, findings indicated that beside enforcement, factors such as driving exposure, attitude toward seat belt use, and respondents' excuses for not wearing a seat belt correlate with seat belt use. One way to incorporate the results of this analysis is to convoy new messages that focus on predictors of seat belt use. Finally, results of the marginal effects could be used for prioritizing the message content by focusing on messages with highest AME. Similarly, demographic variables could be used to target groups that are more prone to seat belt non-use.

It should be noted that stratifying the sample across gender and age could provide insightful information regarding the lower seat belt use of the males and younger population, and consequently will enable practitioners to design educational materials based on high-risk group's needs. This issue needs to be investigated in future studies.

The findings presented a sample of Tennessean respondents, and results cannot be generalized from this setting to others. The study instrument needs further validation in other settings. Social desirability is an important limitation of self-reported questionnaires. Providing a context where the respondents could not be singled out would reduce the negative effect of social desirability. In this study, this setting was provided for respondents to minimize the negative effect of social desirability.

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