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Transportation Development Research

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Spatiotemporal Context for Vehicular Crash Fatalities Days Before and Days After Daylight Saving Time Transitions

Edmund Zolnik [*], ***Patrick Baxter***

DSchar School of Policy and Government, George Mason University, Arlington, Virginia 22201, USA

ABSTRACT

Vehicular crashes are historically a major cause of unintentional death in the United States. The empirical literature on safe transportation is rich with research on how human behavior results in lethal vehicular crash outcomes. Given the stubborn persistence in such outcomes, public policy that may contribute to unintentional deaths is worthy of scrutiny. Annual transitions to and from daylight saving time (DST) are an example. Unfortunately, agreement on the sign and magnitude of the effect of DST transitions on vehicular crash fatalities is scarce in the empirical literature. Further, notable gaps in the empirical literature are evident on how to realistically model temporal and spatial heterogeneity in vehicular crash outcomes. To fill this specific gap, the study adopts a multilevel approach to control for temporal and spatial heterogeneity in the specification of a statistical model that pools twenty years of fatal crash data on DST transition days and on days before and after DST transitions. Results suggest the probability of one more vehicular crash fatality increases by +2.29% on the Sunday of the spring transition (ST). Results also suggest the probability of one more vehicular crash fatality increases by +0.99% on the Sunday seven days after the ST. These results highlight the importance of law enforcement interdictions targeting alcohol and drug involvement on the Sunday of the ST and seven days following it, in order to reduce vehicular crash fatalities.

Keywords: Daylight Saving Time (DST); Vehicular Crash Fatalities; Spatiotemporal Context; Multilevel Model; Contiguous United States

*CORRESPONDING AUTHOR:

Edmund Zolnik, Schar School of Policy and Government, George Mason University, Arlington, Virginia 22201, USA; Email: ezolnik@gmu.edu

ARTICLE INFO

Received: 2 July 2024 | Revised: 8 August 2024 | Accepted: 16 September 2024 | Published Online: 29 September 2024

DOI: https://doi.org/10.55121/tdr.v2i2.310

CITATION

Zolnik, E., Baxter, P., 2024. Spatiotemporal Context for Vehicular Crash Fatalities Days Before and Days After Daylight Saving Time Transitions. Transportation Development Research. 2(2): 26–38. DOI: https://doi.org/10.55121/tdr.v2i2.310

1. Introduction

The annual number of fatal vehicular crashes is remarkably consistent [1]. Such crashes are presently the number two cause of unintentional death in the United States [2]. Further, the present trend in the annual number of fatal vehicular crashes in the United States is worrisome [3]. Indeed, a −2.03% decrease from 2022 to 2021 follows a +10.96% increase from 2021 to 2020 and an +8.26% increase from 2020 to 2019. Research in the field of safe transportation on the frequency and severity of vehicular crashes is therefore vitally important. Also vitally important is research on public policy which may unintentionally contribute to the annual number of fatal vehicular crashes. Daylight saving time (DST) is an example of a public policy that may contribute to the annual number of fatal vehicular crashes. On the one hand, the intentional benefit of DST may be a decrease in energy demand since DST increases natural light when the majority of people are active via seasonal shifts in clock time relative to solar time [4,5]. On the other hand, the unintentional cost of DST may be a decrease in transportation safety since seasonal shifts in clock time relative to solar time decrease natural light when the majority of drivers are active [6].

The safety effect of DST transitions on vehicular crashes emanates from the following phenomena [7]. The DST-transition safety effect represents the phenomenon where drivers subtract one hour of sleep at the spring (forward) transition and drivers add one hour of sleep at the fall (backward) transition. The loss of sleep on the spring transition (ST) day and the gain of sleep on the fall transition (FT) day adversely affect driver behavior. From the spring to the fall, the loss of sleep from the former transition more adversely affects driver behavior than the gain of sleep from the latter transition. The time-of-day safety effect represents the phenomenon where DST transitions change clock time relative to solar time. The spring (forward) transition adds one hour of light relative to clock time. The fall (back) transition subtracts one hour of light relative to clock time. After the ST, more light later in the day increases safety at a time of the day when trips are more numerous. After the FT, less light later in the day decreases safety at a time of the day when trips are more numerous.

Unfortunately, a critical analysis of the empirical literature on the safety effect of DST transitions reveals the signs and magnitudes of the results are inconsistent, at best. Data are usually from a national census of fatal crashes in the United States known as the Fatality Analysis Reporting System (FARS) [8], so the inconsistent results are probably due to differences in time and design. The trajectory of the research is to analyze more data by year to obviate problems with trends. On the one hand, Meyerhoff analyzes two years of data on fatal crashes [9]. On the other hand, Fritz et al. analyze twenty-two years of data on fatal crashes [7]. Differences in time aside, differences in design are noteworthy. Designs to isolate the effect of DST transitions on safe transportation usually adopt a difference-in-difference approach [9–11]. A difference-in-difference approach to DST transitions is quasi-experimental since the design exploits changes in DST [12]. For example, the Energy Policy Act of 2005 (Public Law 109-58) changes DST in 2007 from the second Sunday of March to the first Sunday of November.

Research that adopts a difference-in-difference approach highlights important questions on annual, seasonal, monthly, weekly, daily, and hourly variation in vehicular crash outcomes irrespective of DST transitions [10,11]. Indeed, isolation of the effect of DST transitions presumes the temporal context for fatal vehicular crash outcomes is understood, but such a presumption is questionable. The present study, therefore, aims to control for daily variation in fatal crash outcomes days before and after DST transitions to better understand the temporal context for fatal crash outcomes. Specifically, the temporal dimension is the day of the crash, the spatial dimensions are the latitude and longitude of the crash, and the outcome is the number of fatalities in the crash. Moreover, rather than adopt a design to exploit changes in the Sunday of the ST and FT [10,11], the design harmonizes the Sunday of the ST and FT from 2001 to 2020. To do so, the design pools twenty years of fatal crash data for each of the seven days before the ST day, each ST day, and each of the seven days after the ST day as well as for each of the seven days before the FT day, each FT day, and each of the seven days after the FT day to estimate a day effect irrespective of year. The design therefore isolates the disaggregate safety effects of ST-DST transitions in the spring and DST-FT transitions in the fall from 2001 to 2020. Such a design obviates the problematic assumptions of no changes in annual and seasonal trends [10,11]. Such a design also obviates the problematic assumptions of no changes in days-before-transitions, days-of-transitions, and days-after-transitions trends [9,11,13]. Overall, the design helps to better understand the temporal context for fatal vehicular crash outcomes days before and after DST transitions.

The outline of the study is as follows. The literature review section reviews the empirical literature on DST-transition safety effects. The data and methodology sections, respectively, list the variables and specify the models. The results section presents the results and the discussion section interprets the results. The conclusions section highlights the contributions and limitations of the study and the trajectory of future research.

2. Literature Review

The study area is the contiguous United States. So, to harmonize the results with the literature the following review is specific to research on the safety effects of DST transitions in the contiguous United States.

A critical review of the empirical literature specific to the contiguous United States from 1978 to 2022 reveals DST transitions decrease and increase fatalities [9,14]. From March of 1974 and April of 1974 (with DST) to March of 1973 and April of 1973 (without DST), net vehicular crash fatalities decreased by −0.70% [9]. From 1987 to 1991, fatal vehicular crashes decreased by approximately 901 if DST is permanent [15]. From 1975 to 1995, fatal vehicular crashes increased on the Monday after the ST day, and fatal vehicular crashes increased on the Sunday of the FT [13]. From 1976 to 2003, analysis of an experimental subsample of fatal crashes before STs versus a control subsample of fatal crashes after STs reveals fatal pedestrian crashes decreased from −8.00% to −11.00% in the long run after STs and fatal vehicular crashes decreased from −6.00% to −10.00% in the long run after STs [11]. From 2002 to 2011, fatal vehicular crashes increase from +5.00% to +6.50% after the ST [10]. From 1996 to 2017, fatal vehicular crash risk increases by approximately +6.00% in the week of the ST (Monday to Friday) [7]. From 2014 to 2016, vehicular crash frequency in six states representative of the different time zones decreased by −18.20% in the eight-week period after the springtime change and increased by +6.22% in the four-week period after the fall time change [14]. Interestingly, Zhou and Li also found that the impact of the springtime change was greater if the crash was less severe [14]. Such a result may help to understand why analyses of vehicular crash fatalities show an increase after the springtime change.

The following section presents the variable list.

3. Data

The contribution of the study to the empirical literature on DST-transition safety effects emanates from the limitations of the timeliest research [7,14]. Specifically, the analysis includes information on the number of persons with Blood Alcohol Concentration (BAC) greater than 0.00 grams per deciliter and the number of persons with police reports of drug involvement. The inclusion of information on such involvement is important because alcohol and drugs are prevalent in injurious and fatal crashes [16]. Indeed, alcohol and marijuana rank first and second as the most detectable psychoactive substances in the population of drivers [17]. The analysis also includes information on light and weather conditions at the time of the crash. This data is crucial, as transitions between light and dark (e.g., sunrise and sunset), along with adverse weather, are known to increase crash risks [1,15]. Finally, the analysis includes information on temporal and spatial heterogeneity in the crash-level data attributable to differences from state to state in crash exposure (aggregate travel demand, licensed drivers, and registered vehicles).

The data dictionary for the dependent and independent variables is presented in **Table 1**. Descriptive statistics for crashes, days, and states are in **Table 2**.

Table 1. Data Dictionary for Crash, Day, and State Levels.

Level	Variable	Description
Crash		
Dependent		
	Fatalities	Number of fatalities.
	Natural Log Fatalities	Natural log of the number of fatalities.
Independent		
	Alcohol	Number of persons with BAC[1] greater than 0.00 grams per deciliter.
	Drugs	Number of persons police report drug involvement.
	Latitude (Decimal Degrees)	Geographic location in global position coordinates from police crash report.
	Light	Light conditions at time of crash. If time of crash is at dawn or at dusk, then Light = 1; 0 otherwise.
	Longitude (Decimal Degrees)	Geographic location in global position coordinates from police crash report.
	Speed	Number of speed-involved vehicles.
	Vehicles	Number of vehicles.
	Weather	Atmospheric conditions at time of crash. If atmospheric conditions are adverse at time of crash, then Weather = 1; 0 otherwise.
	Zone	Time zone for geographic location of crash.
Day		
	ST − 7	If crash is on ST minus seven, then ST − 7 = 1; 0 otherwise.
	ST − 6	If crash is on ST minus six, then ST − 6 = 1; 0 otherwise.
	ST − 5	If crash is on ST minus five, then ST − 5 = 1; 0 otherwise.
	ST − 4	If crash is on ST minus four, then ST − 4 = 1; 0 otherwise.
	ST − 3	If crash is on ST minus three, then ST − 3 = 1; 0 otherwise.
	ST − 2	If crash is on ST minus two, then ST − 2 = 1; 0 otherwise.
	ST − 1	If crash is on ST minus one, then ST − 1 = 1; 0 otherwise.
	ST	If crash is on ST, then ST = 1; 0 otherwise.
	ST + 1	If crash is on ST plus one, then ST + 1 = 1; 0 otherwise.
	ST + 2	If crash is on ST plus two, then ST + 2 = 1; 0 otherwise.
	ST + 3	If crash is on ST plus three, then ST + 3 = 1; 0 otherwise.
	ST + 4	If crash is on ST plus four, then ST + 4 = 1; 0 otherwise.
	ST + 5	If crash is on ST plus five, then ST + 5 = 1; 0 otherwise.
	ST + 6	If crash is on ST plus six, then ST + 6 = 1; 0 otherwise.
	ST + 7	If crash is on ST plus seven, then ST + 7 = 1; 0 otherwise.
	FT − 7	If crash is on FT minus seven, then FT − 7 = 1; 0 otherwise.
	FT − 6	If crash is on FT minus six, then FT − 6 = 1; 0 otherwise.
	FT − 5	If crash is on FT minus five, then FT − 5 = 1; 0 otherwise.
	FT − 4	If crash is on FT minus four, then FT − 4 = 1; 0 otherwise.
	FT − 3	If crash is on FT minus three, then FT − 3 = 1; 0 otherwise.
	FT − 2	If crash is on FT minus two, then FT − 2 = 1; 0 otherwise.
	FT − 1	If crash is on FT minus one, then FT − 1 = 1; 0 otherwise.
	FT	If crash is on FT, then FT = 1; 0 otherwise.
	FT + 1	If crash is on FT plus one, then FT + 1 = 1; 0 otherwise.
	FT + 2	If crash is on FT plus two, then FT + 2 = 1; 0 otherwise.
	FT + 3	If crash is on FT plus three, then FT + 3 = 1; 0 otherwise.
	FT + 4	If crash is on FT plus four, then FT + 4 = 1; 0 otherwise.
	FT + 5	If crash is on FT plus five, then FT + 5 = 1; 0 otherwise.
	FT + 6	If crash is on FT plus six, then FT + 6 = 1; 0 otherwise.
	FT + 7	If crash is on FT plus seven, then FT + 7 = 1; 0 otherwise.
State		
	Aggregate Travel Demand	Vehicle Kilometers of Travel (VKT).
	Licensed Drivers	Licensed drivers per 1,000 driving-age population.
	Aggregate Road Supply (Lane-Kilometers)	Functional road system.
	Poor-Quality Road Surfaces (Percent)	Percent of poor-quality road surfaces.
	Registered Vehicles	Automobiles (private and commercial).

[1]BAC = Blood Alcohol Concentration.

Table 2. Descriptive Statistics for Crash, Day, and State Levels.

Level (n)			
Variable		**M[1]/Y[2]**	**SD[3]/N[4]**
Crash (632,014)			
Dependent			
	Fatalities	1.09	0.36
	Natural Log Fatalities	0.06	0.21
Independent			
	Alcohol	2.44	1.46
	Drugs	0.09	0.30
	Latitude (Decimal Degrees)	+36.59	5.00
	Light (Percent)	4.15	95.85
	Longitude (Decimal Degrees)	−91.67	14.17
	Speed	0.29	0.46
	Vehicles	1.49	0.64
	Weather (Percent)	18.89	81.11
	Zone (Percent)		
	Eastern	45.43	
	Central	35.02	
	Mountain	6.43	
	Pacific	13.12	
Day (17,758)			
	ST − 7 (Percent)	0.27	99.73
	ST − 6 (Percent)	0.22	99.78
	ST − 5 (Percent)	0.20	99.80
	ST − 4 (Percent)	0.22	99.78
	ST − 3 (Percent)	0.22	99.78
	ST − 2 (Percent)	0.27	99.73
	ST − 1 (Percent)	0.31	99.69
	ST (Percent)	0.28	99.72
	ST + 1 (Percent)	0.23	99.77
	ST + 2 (Percent)	0.23	99.77
	ST + 3 (Percent)	0.23	99.77
	ST + 4 (Percent)	0.23	99.77
	ST + 5 (Percent)	0.29	99.71
	ST + 6 (Percent)	0.32	99.68
	ST + 7 (Percent)	0.27	99.73
	FT − 7 (Percent)	0.32	99.68
	FT − 6 (Percent)	0.25	99.75
	FT − 5 (Percent)	0.25	99.75
	FT − 4 (Percent)	0.26	99.74
	FT − 3 (Percent)	0.26	99.74
	FT − 2 (Percent)	0.34	99.66
	FT − 1 (Percent)	0.36	99.64
	FT (Percent)	0.33	99.67
	FT + 1 (Percent)	0.25	99.75
	FT + 2 (Percent)	0.25	99.75
	FT + 3 (Percent)	0.26	99.74
	FT + 4 (Percent)	0.26	99.74
	FT + 5 (Percent)	0.31	99.69
	FT + 6 (Percent)	0.36	99.64
	FT + 7 (Percent)	0.31	99.69
State (49)			
Independent			
	Aggregate Travel Demand	98,459.67	99,758.85
	Licensed Drivers	903.86	51.48
	Aggregate Road Supply (Lane-Kilometers)	279,853.41	184,231.34
	Poor-Quality Road Surfaces (Percent)	9.41	12.23
	Registered Vehicles	2,489,722.43	2,832,015.85

[1]M = Mean. [2]Y = Yes. [3]SD = Standard Deviation. [4]N = No.

The dependent variables at the crash level (n = 632,014) are: the number of fatalities and the natural log of the number of fatalities [8].

The independent variables at the crash level are: the number of persons with BAC greater than 0.00 grams per deciliter [18–23]; the number of persons police report drug involvement [24,25]; the latitude in decimal degrees from the police crash report; light conditions at the time of the crash; the longitude in decimal degrees from the police crash report; the number of speed-involved vehicles; the number of vehicles; weather conditions at the time of the crash; and the time zone [8]. The number of persons with BAC greater than 0.00 grams per deciliter uses a new methodology (multiple imputation) to estimate BAC values from 0.00 grams per deciliter to 0.94 grams per deciliter. Drug involvement is not drug impairment. Adverse atmospheric conditions are: rain (mist) (from 2001 to 2009) or rain (from 2010 to 2020); sleet (hail) (from 2001 to 2009), sleet, hail (freezing rain or drizzle) (from 2010 to 2012) or sleet, hail (from 2013 to 2020); snow (from 2001 to 2006), snow or blowing snow (from 2007 to 2009) or snow (from 2010 to 2020); fog (2001 to 2006) or fog, smog or smoke (from 2007 to 2020); rain and fog (from 2001 to 2006) or severe crosswinds (from 2007 to 2020); sleet and fog (from 2001 to 2006) or blowing sand, soil or dirt (from 2007 to 2020); and other smog, smoke, blowing sand or dust (from 2001 to 2006) or other (from 2007 to 2020). No adverse atmospheric conditions (from 2001 to 2006), clear/cloud (no adverse conditions) (from 2007 to 2009), or clear (from 2010 to 2020) are not adverse conditions. Time zones are Eastern, Central, Mountain, or Pacific.

The independent variables at the day level (n = 17,758) are as follows. ST – 7, ST – 6, ST – 5, ST – 4, ST – 3, ST – 2, and ST – 1 are seven, six, five, four, three, two, and one day, respectively, before the ST day. ST + 1, ST + 2, ST + 3, ST + 4, ST + 5, ST + 6, and ST + 7 are one, two, three, four, five, six, and seven days, respectively, after the ST. FT – 7, FT – 6, FT – 5, FT – 4, FT – 3, FT – 2, and FT – 1 are seven, six, five, four, three, two, and one day, respectively, before the FT day. FT + 1, FT + 2, FT + 3, FT + 4, FT + 5, FT + 6, and FT + 7 are one, two, three, four, five, six, and seven days, respectively, after the FT. The day level excludes February 29th in leap years (2004, 2008, 2012, 2016, and 2020).

The independent variables at the state level (n = 49) are: the mean kilometers of travel; the mean number of licensed drivers; the mean lane-kilometers of road; the mean percent of poor-quality road surfaces [26,27]; and the mean number of registered vehicles from 2001 to 2020 [28]. The state level includes the District of Columbia, but excludes Alaska and Hawaii. The mean number of licensed drivers includes restricted-license and graduated-license drivers. The mean lane-kilometers of road includes (rural and urban): interstates; other freeways and expressways; other principal arterials; minor arterials; major collectors; minor collectors; local roads; and unknown roads. The mean percent of poor-quality road surfaces represents an International Roughness Index greater than 170 and excludes data for 2010. The mean number of registered vehicles includes taxicabs.

Section 4 describes the method and model used in the study.

4. Methodology

Adoption of a multilevel approach contextualizes crash fatalities days before and after DST transitions. Justification for such an approach is as follows. First, the second and third levels of the model, respectively, explicitly nest crash outcomes within temporal and spatial dimensions of analysis. Second, a multilevel approach more realistically models the nonindependence, or autocorrelation, of crash outcomes by time and space than dummy variables for temporal and spatial covariates because time and space are different levels of analysis [29]. Third, a multilevel model pools information for days and states to estimate the respective contributions of the temporal and spatial dimensions of analysis to variation in the number of fatalities and the natural log of the number of fatalities.

4.1. Multilevel Model

The multilevel model is a three-level model of crashes (c) at the micro level nested within days (d) at the meso level nested within states (s) at the macro level [30]. The specification of the model is as follows.

Within each state, the models for the number of fatalities or the natural log of the number of fatalities are a function of independent variables plus an error term at the crash level:

$$Y_{cds} = \beta_{0ds} + \beta_{1ds}W_{1cds} + \ldots + \beta_{Ads}W_{Acds} + r_{cds}, \quad (1)$$

where Y_{cds} is the number of fatalities or the natural log of the number of fatalities in crash c on day d in state s; β_{0ds} is the y-intercept term for day d in state s; β_{Ads} are a = 1, …, A coefficients at the crash level; W_{Acds} are a = 1, …, A independent variables at the crash level; and r_{cds} is the random effect term at the crash level.

The model for variation between days within states is as follows:

$$\beta_{0ds} = \pi_{00s} + \pi_{01s}X_{1ds} + \ldots + \pi_{0Cs}X_{Cds} + e_{0ds}, \quad (2)$$

where π_{00s} is the y-intercept term for state s; π_{0Cs} are c = 1, …, C coefficients at the day level; X_{Cds} are c = 1, …, C independent variables at the day level; and e_{0ds} is the random effect term at the day level.

The model for variation between states is as follows:

$$\pi_{00s} = \gamma_{000} + \gamma_{001}Z_{1s} + \ldots + \gamma_{00B}Z_{Bs} + u_{00s}, \quad (3)$$

where γ_{000} is the y-intercept term for state s; γ_{00B} are b = 1, …, B coefficients at the state level; Z_{Bs} are b = 1, …, B independent variables at the state; and u_{00s} is the random effect term at the state level.

The three-level model is known as a random-intercepts model where the y-intercepts at the day and state levels are random, but the coefficients at the day and state levels are fixed.

5. Results

5.1. Descriptive Statistics

Estimates from random-intercept models for Fatalities and Natural Log Fatalities are in **Table 3**. The left column (Fatalities) presents estimates for the dependent variable the number of fatalities. The right column (Natural Log Fatalities) presents estimates for the dependent variable the natural log of the number of fatalities. The following subsections present the random-intercept model results at the crash, day, and state levels.

Table 3. Estimates from Random-Intercept Models for Fatalities and Natural Log Fatalities.

Level (*N*)	Variable	Fatalities		Natural Log Fatalities	
		Coefficient (SE[1])	*P*[2]	Coefficient (SE)	*p*
Crash (632,014)					
	Alcohol[3]	+0.08 (< 0.01)	< 0.01	+0.05 (< 0.01)	< 0.01
	Drugs	+0.03 (< 0.01)	< 0.01	+0.02 (< 0.01)	< 0.01
	Latitude (Decimal Degrees)	+0.002 (< 0.01)	= 0.05	+0.001(< 0.01)	= 0.03
	Light (Dawn/Dusk = 1/Otherwise = 0)	+0.01 (< 0.01)	< 0.01	+0.003 (< 0.01)	= 0.01
	Longitude (Decimal Degrees)	−0.001 (< 0.01)	< 0.01	−0.001 (< 0.01)	< 0.01
	Speed	+0.04 (< 0.01)	< 0.01	+0.03 (< 0.01)	< 0.01
	Vehicles	−0.03 (< 0.01)	< 0.01	−0.02 (< 0.01)	< 0.01
	Weather (Adverse = 1/Otherwise = 0)	−0.0005 (< 0.01)	= 0.70	−0.0002 (< 0.01)	= 0.79
	Zone				
	Eastern	Referent[4]	Referent	Referent	Referent
	Central	+0.01 (< 0.01)	= 0.39	+0.004 (< 0.01)	= 0.43
	Mountain	−0.03 (= 0.01)	= 0.01	−0.02 (= 0.01)	= 0.01
	Pacific	−0.06 (= 0.02)	< 0.01	−0.04 (= 0.01)	< 0.01
Day (17,758)					
	ST − 7 (Y[5] = 1/N[6] = 0)	−0.01 (= 0.01)	= 0.46	−0.003 (< 0.01)	= 0.51
	ST − 6 (Y = 1/N = 0)	+0.01 (= 0.01)	= 0.25	+0.01 (< 0.01)	= 0.20
	ST − 5 (Y = 1/N = 0)	+0.01 (= 0.01)	= 0.41	+0.002 (< 0.01)	= 0.66
	ST − 4 (Y = 1/N = 0)	−0.01 (= 0.01)	= 0.54	−0.003 (< 0.01)	= 0.58
	ST − 3 (Y = 1/N = 0)	−0.004 (= 0.01)	= 0.59	−0.003 (< 0.01)	= 0.59
	ST − 2 (Y = 1/N = 0)	+0.001 (= 0.01)	= 0.93	+0.001 (< 0.01)	= 0.82
	ST − 1 (Y = 1/N = 0)	−0.0004 (= 0.01)	= 0.96	+0.001 (< 0.01)	= 0.88

Level (*N*)	Variable	Fatalities		Natural Log Fatalities	
		Coefficient (SE[1])	*P*[2]	Coefficient (SE)	*p*
	ST (Y = 1/N = 0)	+0.04 (= 0.01)	< 0.01	+0.02 (< 0.01)	< 0.01
	ST + 1 (Y = 1/N = 0)	+0.01 (= 0.01)	= 0.22	+0.005 (< 0.01)	= 0.37
	ST + 2 (Y = 1/N = 0)	+0.01 (= 0.01)	= 0.40	+0.003 (< 0.01)	= 0.36
	ST + 3 (Y = 1/N = 0)	+0.01 (= 0.01)	= 0.33	+0.004 (< 0.01)	= 0.35
	ST + 4 (Y = 1/N = 0)	+0.01 (= 0.01)	= 0.14	+0.01 (< 0.01)	= 0.11
	ST + 5 (Y = 1/N = 0)	−0.01 (= 0.01)	= 0.12	−0.01 (< 0.01)	= 0.05
	ST + 6 (Y = 1/N = 0)	−0.01 (= 0.01)	= 0.09	−0.01 (< 0.01)	= 0.12
	ST + 7 (Y = 1/N = 0)	+0.02 (= 0.01)	= 0.05	+0.01 (< 0.01)	= 0.06
	FT − 7 (Y = 1/N = 0)	−0.0002 (= 0.01)	= 0.98	+0.001 (< 0.01)	= 0.79
	FT − 6 (Y = 1/N = 0)	+0.001 (= 0.01)	= 0.91	−0.0005 (< 0.01)	= 0.88
	FT − 5 (Y = 1/N = 0)	+0.003 (= 0.01)	= 0.77	+0.001 (< 0.01)	= 0.92
	FT − 4 (Y = 1/N = 0)	+0.005 (= 0.01)	= 0.47	+0.001 (< 0.01)	= 0.86
	FT − 3 (Y = 1/N = 0)	+0.003 (= 0.01)	= 0.68	+0.003 (< 0.01)	= 0.57
	FT − 2 (Y = 1/N = 0)	+0.002 (= 0.01)	= 0.84	+0.002 (< 0.01)	= 0.63
	FT − 1 (Y = 1/N = 0)	+0.01 (= 0.01)	= 0.16	+0.01 (< 0.01)	= 0.10
	FT (Y = 1/N = 0)	−0.01 (= 0.01)	= 0.40	−0.003 (< 0.01)	= 0.46
	FT + 1 (Y = 1/N = 0)	−0.01 (= 0.01)	= 0.46	−0.004 (< 0.01)	= 0.36
	FT + 2 (Y = 1/N = 0)	+0.002 (= 0.01)	= 0.85	+0.001 (< 0.01)	= 0.86
	FT + 3 (Y = 1/N = 0)	−0.01 (= 0.01)	= 0.39	−0.004 (< 0.01)	= 0.40
	FT + 4 (Y = 1/N = 0)	+0.001 (= 0.01)	= 0.86	+0.001 (< 0.01)	= 0.86
	FT + 5 (Y = 1/N = 0)	−0.01 (= 0.01)	= 0.14	−0.005 (< 0.01)	= 0.20
	FT + 6 (Y = 1/N = 0)	−0.01 (= 0.01)	= 0.23	−0.005 (< 0.01)	= 0.26
	FT + 7 (Y = 1/N = 0)	+0.01 (= 0.01)	= 0.46	+0.004 (< 0.01)	= 0.48
State (49)					
	Intercept	+1.10 (< 0.01)	< 0.01	+0.06 (< 0.01)	< 0.01
	Licensed Drivers	+0.00004 (< 0.01)	= 0.42	+0.00002 (< 0.01)	= 0.41
	Poor-Quality Road Surfaces	−0.001 (< 0.01)	= 0.01	−0.0003 (< 0.01)	= 0.01

[1]SE = Standard Error. [2]*p* = *p*-Value. [3]First BAC imputation. [4]Referent time zone is the time zone with the highest percentage of fatal crashes (45.43%). [5]Y = Yes. [6]N = No.

5.2. Random-Intercept Model Results at Crash Level

Consistent with the empirical literature [31], the number of fatalities increases by +4.60% as the number of persons with BAC greater than 0.00 grams per deciliter increases (**Table 3**). The number of fatalities also increases by +2.01% as the number of persons police report drug involvement increases. The number of fatalities increases slightly by +0.10% as the latitude in decimal degrees increases from south to north. The number of fatalities also increases slightly by +0.31% if light conditions at the time of the crash are at dawn or dusk [32]. Consistent with the empirical literature [7], the number of fatalities decreases by −0.08% as the longitude increases from west to east. The number of fatalities increases by +2.69% as the number of speed-involved vehicles increases, but the number of fatalities decreases by −1.72% as the number of vehicles increases. Finally, the number of fatalities decreases by −2.10% from the Eastern to Mountain time zones and by −3.72% from the Eastern to Pacific time zones.

5.3. Random-Intercept Model Results at Day Level

Fifteen coefficients from seven days before the ST (ST − 7) day to seven days after the ST (ST + 7) day, ST day inclusive, represent the effect of day on the number of fatalities (**Table 3**). Consistent with the empirical literature on DST transitions [7], three coefficients for the effect of day on the number of fatalities from seven days before the ST (ST − 7) day to seven days after the ST (ST + 7) day, ST day inclusive, are statistically significant. Specifically, the number of fatalities: increases by +2.29% on the ST day ($p < 0.01$); decreases by −0.70% five days after the ST (ST + 5) day ($p < 0.05$); and increases by +0.99% seven days after the ST (ST + 7) day ($p < 0.10$) (**Figure 1**).

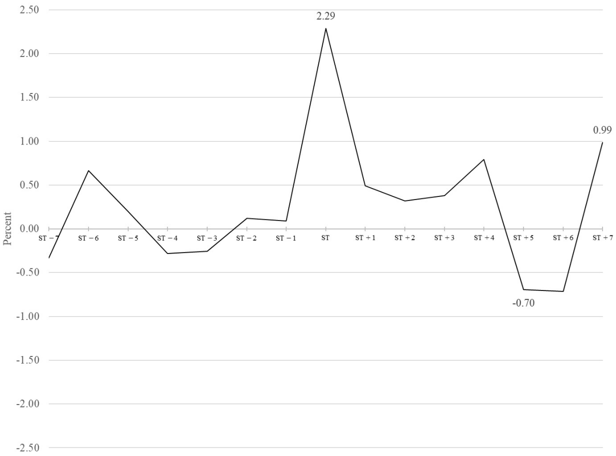

Figure 1. Effect of Day on the Number of Fatalities from Seven Days Before the Spring Transition (ST − 7) Day to Seven Days After the Spring Transition (ST + 7) Day, Spring Transition (ST) Day Inclusive.

Fifteen coefficients from seven days before the FT (FT − 7) day to seven days after the FT (FT + 7) day, FT day inclusive, represent the effect of day on the number of fatalities (**Table 3**). Inconsistent with the empirical literature on DST transitions [7], zero coefficients for the effect of day on the number of fatalities from seven days before the FT (FT − 7) day to seven days after the FT (FT + 7) day, FT day inclusive, are statistically significant (**Figure 2**).

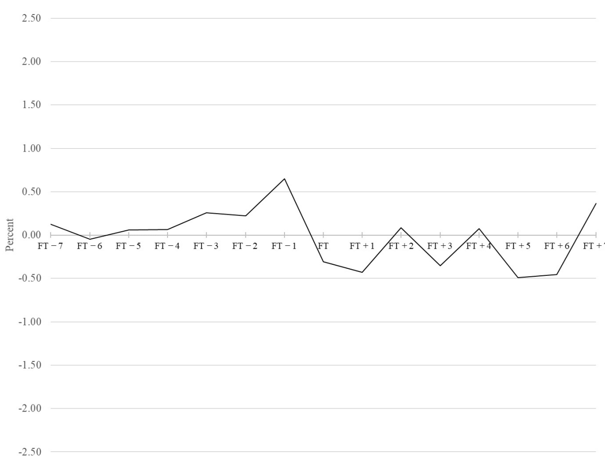

Figure 2. Effect of Day on the Number of Fatalities from Seven Days Before the Fall Transition (FT − 7) Day to Seven Days After the Fall Transition (FT + 7) Day, Fall Transition (FT) Day Inclusive.

5.4. Random-Intercept Model Results at State Level

Full models at the macro-level fail to converge (**Table 3**). The problem with the fixed portions of the full models is multicollinearity between the state-level independent variables. Indeed, the linear associations between the mean kilometers of travel and the mean lane-kilometers of road ($r = +0.76$; $p < 0.0001$), the mean kilometers of travel and the mean number of registered vehicles ($r = +0.97$; $p < 0.0001$), and the mean lane-kilometers of road and the mean number of registered vehicles ($r = +0.66$; $p < 0.0001$) are statistically significant. The models which converge without errors and yield interpretable estimates specify the mean number of licensed drivers and the percent poor-quality road surfaces at the macro level. The linear association between the mean number of licensed drivers and the percent poor-quality road surfaces (r = −0.44; p = 0.0015) is also statistically significant. Finally, the number of fatalities decreases slightly by −0.03% as the percent of poor-quality road surfaces increases probably due to slower speeds [33].

5.5. Intraclass Correlation Coefficient (ICC)

The intraclass correlation coefficient (ICC) estimates the correlation in the number of fatalities between two random crashes on the same day and in the same state [30,34]. The ICC for the random-intercept model is 0.13%. The explained proportion of variance between a full and null random-effects model is an analog to the coefficient of determination (R^2) for a fixed-effect model [35]. The explained proportion of variance between the full and null models is 9.14%. Interpretation of the explained proportion of variance is as follows. The crash-level, day-level, and state-level independent variables explain 9.14% of the variance in the crash-level dependent variable (number of fatalities).

6. Discussion

Analysis of DST-transition safety effects days before and after DST transitions reveals the following.

At the crash level, the increase in the number of fatalities as the number of persons with BAC greater than 0.00 grams per deciliter increases and the increase in the number of fatalities as the number of persons police report drug involvement increases represent days, particularly the ST day and ST + 7 day, when interdiction to enforce laws against alcohol and drug impairment are especially efficacious [36]. The slight increase in the number of fatalities as latitude in decimal degrees increases from south to north probably represents greater seasonal variation in the clock times of sunrise and sunset at the northern extent of the contiguous United States (+49) than at the southern extent of the contiguous United States (+25) [5]. The slight increase in the number of fatalities if light conditions at the time of the crash are at dawn or dusk represents the decrease in safety attributable to the one-hour change in the clock times of sunrise and sunset on the ST and ST + 7 days. The slight decrease in the number of fatalities as longitude in decimal degrees increases from west to east represents the phenomenon known as the time-zone safety effect [7]. At the same clock time, the sun rises later at the western extent of a time zone relative to the eastern extent of a time zone. Such a western-eastern difference within a time zone between clock and solar times explains why more eastern locations experience more light early in the day and more western locations experience less light early in the day. Overall, light conditions early in the day are safer in the former than in the latter within a time zone. The decrease in the number of fatalities from the Eastern to the Mountain time zone, and from the Eastern to the Pacific time zone, is an artifact of the disparity in the percentage of crashes: 45.43% in the Eastern time zone, 6.43% in the Mountain time zone, and 13.12% in the Pacific time zone.

At the day level, the increase in the number of fatalities on the ST and ST + 7 days are noteworthy results. The latter result is especially noteworthy since Fritz et al. also report a "…risk increase on the DST Sunday…" but no risk increase "…on the following weekend" [7]. Interestingly, such results are consistent and inconsistent with the empirical literature on the safety effect of DST transitions [7,9–11,13,15]. On the one hand, Smith reports the change in fatal crash risk at the ST from standard time to DST is statistically significant (positive) [10], but the change in fatal crash risk at the FT from DST to standard time is not statistically significant. On the other hand, Varughese and Allen report the mean number of fatal crashes on the Sunday of the ST is not statistically significant [13], but the mean number of fatal crashes on the Sunday of the FT is statistically significant (positive). Why present results are consistent and inconsistent with past results is probably due to differences in dimensions, outcome, and design. To reiterate, the temporal dimension is the day, the spatial dimension is the latitude/longitude, and the outcome is the number of fatalities. Importantly, the design harmonizes the Sundays of the ST and FT to isolate the disaggregate safety effect of ST-DST transitions in the spring and DST-ST transitions in the fall. Overall, the innovative design yields new results (**Figure 1**) on the specificity of the temporal context for the DST-transition safety effect by season (spring) and day (Sunday).

At the state level, the decrease in the number of fatalities as the percent of poor-quality road surfaces increases is probably an artifact of multicollinearity between the independent variables. Empirical evidence for such a conclusion is as follows. First, the negative effect is statistically significant (p = 0.013), but the magnitude of the negative effect is slight (−0.03%). Second, the linear association between the mean number of licensed drivers and the percent of poor-quality road surfaces is negative and statistically significant (r = −0.44; p = 0.0015). Third, the linear associations between the mean number of licensed drivers and: the mean kilometers of travel (r = −0.36; p = 0.0109); the mean lane-kilometers of road (r = −0.26; p = 0.0702); and the mean number of registered vehicles (r = −0.38; p = 0.0071) are also negative in sign and statistically significant. Importantly, the magnitude of the linear association is greatest for the percent of poor-quality road surfaces. Fourth, the sign of the linear association between the mean number of motor-vehicle crash fatalities on the functional road system of the state and the percent of poor-quality road surfaces in the state is also negative, but not statistically significant (r = −0.08; p = 0.5719). Therefore, the counterintuitive sign of the effect at the most disaggregate level of analysis is consistent with the sign of the effect of motor-vehicle fatalities at the most aggregate level of analysis. Overall, the interaction between the mean number of licensed drivers and the percent of poor-quality road surfaces probably represents a scale effect for active users of the functional road system in each state where more drivers demand smoother road surfaces.

7. Conclusions

Seasonal and day-of-the-week periodicity in the number of fatalities highlight the important contribution of the study to the empirical literature on DST-transition safety effects. The dangers attributable to alcohol and drug involvement suggests a seven-day lag from the Sunday of the ST day to the Sunday of the ST + 7 day in the interaction between involvement and sleep [11,31]. Empirical evidence of a seven-day lag after the springtime change also supports the argument that the DST-transition safety effect persists [14,37]. Such results are especially helpful to formulate government safety countermeasures and target law enforcement interdictions to efficaciously offset danger on the ST and ST + 7 days consistent with the National Roadway Safety Strategy [36]. Examples include stringent driving while intoxicated (DWI) laws and harmonization of driving under the influence of drugs (DUID) laws [38,39].

The limitations of the study are as follows. The coefficient and standard error estimates for Alcohol in **Table 3** result from analysis of the first imputation of BAC values from 2001 to 2020. Results from only the first imputation limits estimation of within-imputation and between-imputation variance [40]. Preliminary analyses of the second imputation to the tenth imputation of BAC values from 2001 to 2020 suggests within-imputation and between-imputation variance are not problematic. The omission of data on the travel speed of the vehicle prior to the occurrence of the crash limits analysis of the interaction between impairment and speed and limits analysis of the interaction between sleep and speed [8,11,41,42]. The officer who investigates the crash reports an estimate of travel speeds after the crash so data are often a judgement of travel speed, not a measurement of travel speed. Also, data are often unknown. Efforts are ongoing to obviate the above problems with missing data on travel speed which Sood and Ghosh also highlight [11]. To that end, the inclusion of the number of speed-involved vehicles approximates, at best, how speed contributes to vehicular crash fatalities [36]. The omission of data to analyze day-of-the-year, day-of-the-month, and day-of-the-week periodicity in the number of fatalities limits the generalizability of the results to the empirical literature on the safety effect of DST transitions. Such analyses are important because the contributions of the study on seasonal and day-of-the-week periodicity in the number of fatalities may represent an artifact of changes in the number of fatalities not attributable to DST transitions even if driver performance decreases at the standard time to DST transition [11,43].

One important extension of the study to future research on DST transitions is to use a different spatial dimension of analysis such as school zones. Indeed, research on the safety effect of DST transitions in school zones is longstanding [5,44,45], if not consistent [12]. Of special import is the expectation of lower explanatory effects for alcohol and drug involvement given the time of the day when trips to and from school occur. Repetition of the study with the same data at the crash and day levels, but with different data at the highest level of aggregation (school zone versus state) is therefore ideal to better understand the effects of DST transitions on local crash outcomes.

Author Contributions

Conceptualization, E.Z. and P.B.; methodology, E.Z.; software, E.Z.; validation, E.Z.; formal analysis, E.Z.; investigation, E.Z.; resources, E.Z.; data curation, E.Z.; writing—original draft preparation, E.Z. and P.B.; writing—review and editing, E.Z. and P.B.; visualization, E.Z.; supervision, E.Z.; project administration, E.Z. All authors have read and agreed to the published version of the manuscript.

Funding

This work received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author, E.Z., upon reasonable request.

Acknowledgments

We acknowledge the Schar School of Policy and Government at George Mason University for administrative and technical support.

Conflicts of Interest

The authors declare no conflict of interest.

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