Evaluating Safety Effects of Daylight Savings Time on Fatal and Nonfatal Injury Crashes in Texas

Charles R. Stevens, Jr., and Dominique Lord

Daylight savings time (DST) takes place each year from 2:00 a.m. on the first Sunday in April to 2:00 a.m. on the last Sunday in October. It is expected that the changes to and from DST could positively or negatively affect safety. In fact, previous research has shown that these changes indeed affect safety, but many studies suffered from methodological limitations, including erroneously extrapolating short-term effects to long-term conditions. Given these limitations and contradictory results, there is a need to reexamine the effects of DST on the number of motor vehicle and pedestrian crashes. The primary objective of this study was to quantify the safety effects of DST through the use of statistical modeling for the morning and afternoon 5-h periods at the boundary delimiting dark and light conditions. The secondary objective consisted of conducting a before-and-after study to estimate the immediate effects following the change to and from DST. To quantify the potential safety effects of DST, model outputs were applied to different hypothetical time intervals during the year, including the newly proposed DST extension by the U.S. Congress. The results of the study showed that the statistical models performed as expected, with the exception of one model, with which the number of crashes decreased with an increasing proportion of daylight conditions in the 5-h period. The application of the models to different scenarios showed that the absolute difference in predicted crashes was relatively small between scenarios, a finding that supported previous work on this topic.

Daylight savings time (DST) in the United States—with the exception of Arizona, Hawaii, part of Indiana, America Samoa, Puerto Rico, and the Virgin Islands—occurs at 2:00 a.m. on the first Sunday in April and ends at 2:00 a.m. on the last Sunday in October, with respect to individual time zones (*1*). On the first Sunday in April, the time is adjusted by the addition of 1 h. On the last Sunday in October, the time is adjusted by the subtraction of 1 h. In Great Britain, British summer time (BST), similar to DST, advances time by 1 h starting at 2 a.m. on the morning of the day after the third Saturday in March—or if that is Easter Sunday, the day after the second Saturday—and ends at 2 a.m. on the day after the fourth Saturday in October (*2*).

It is expected that these changes could affect safety, as regular daily routines of road users are changed abruptly. These changes may be more significant in morning and afternoon periods because they occur at the boundary delimiting dark and light conditions (sunrise and sunset). Studies performed in North America and Great Britain that have examined the safety effects of the change to and from DST (or BST) have found that the number of crashes has either increased or decreased following the time change. Past research conducted on the investigation of these effects concentrated on pedestrian collisions and in-vehicle occupant fatalities (*3–7*). In addition, some of these studies suffered from methodological limitations, including linear regression models and erroneous extrapolation of short-term or immediate effects to long-term conditions. Given the limited number of studies on this topic, there is a need to reexamine the effects of DST on the number of motor vehicle and pedestrian crashes.

The primary objective of this study was to quantify the safety effects of DST through the use of statistical modeling. The secondary objective consisted of conducting a before-and-after study to estimate the immediate effects following a change to or from DST. To accomplish these objectives, fatal and nonfatal injury crashes as well as other relevant data involving motor vehicles and pedestrians were collected in nine districts in Texas for 1998 to 2000. The quantification was estimated with the use of statistical models linking crash data to the hours of daylight and season for the morning and afternoon 5-h periods. The immediate effects were estimated via a naïve before-and-after study 5 days before and following the time change in the spring and fall. Following the development of the statistical models, the output of these models was applied to different hypothetical scenarios to quantify the safety effects when DST was applied to different time intervals during the year.

This remainder of this paper is divided into five sections. The first one briefly reviews previous work on the safety effects of DST. The second outlines the data collection effort. The third presents relevant descriptive statistics. The fourth section describes the results of the analyses for quantifying the long- and short-term effects of DST. The last section summarizes the key findings of the study and presents areas for future research.

BACKGROUND

All studies that have examined the safety effects on DST have concluded that the 1-h change to or from DST has either a positive or negative influence on safety. For example, Coate and Markowitz (*3*), in a 2002 study, reviewed fatal vehicular occupant and pedestrian crashes occurring in 1998 and 1999 for the entire United States and

C. R. Stevens, Jr., Texas Transportation Institute, 701 North Post Oak, Suite 430, Houston, TX 77024-3827. D. Lord, Department of Civil Engineering and Center for Transportation Safety, Texas Transportation Institute, Texas A&M University System, 3135 TAMU, College Station, TX 77843-3135.

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found an increase in the number of crashes from October to November around the time changes from DST to normal standard time (NST). Coate and Markowitz also developed statistical models to predict the number of crashes for the peak periods as a function of sunset, vehicle miles, seasons, and weather patterns. They found the marginal effect of sunset on pedestrian fatalities to be −0.8% in the morning and 0.3% in the afternoon peak period, suggesting that a 1-h change in sunset would reduce pedestrian fatalities by 171 per year.

In a similar study, Ferguson et al. investigated the safety effects of varying stages of light conditions on fatal crashes for a 22-week period (*4*). Linear regression models linking fatal injuries to daylight conditions, seasons, and week in the 22-week period were fitted for different morning and afternoon (5-h) periods. The statistical models showed that the effects for season, week, time, the hour within the peak period, and light conditions were found to be significant. Despite the fact that linear models are not adequate for modeling count data, they produced the expected results showing the inverse relationship between lighting conditions and the number of pedestrian and vehicular fatalities; more light during the morning and afternoon periods was associated with a reduction in the number of fatalities. The authors of that study suggested that the effects were more pronounced for pedestrian than for in-vehicle fatalities (*4*).

Green (*5*) conducted a naïve before-and-after study that used data collected 5 days before and after the changes to and from BST. Green reported a 31% reduction in the number of motor vehicle crashes for the change to BST during March and a 64% increase the week following the change back to standard time in October. Both changes were found to be statistically significant (*5*). Green did not account for regression-to-the-mean (RTM) and site selection biases for the before-and-after evaluation.

Hillman (*6*), reviewing research done by Green (*5*), associated cost savings by using the Great Britain Department of Transport's ratio of fatalities to serious injuries. Hillman's study showed a reduction of 63 fatal crashes for 1988 as well as a decrease in both serious and minor injuries. Expanding on Green's conclusions (i.e., expanding the results of a study of short-term effects to long-term application), Hillman suggested that governmental savings due to BST was in the range of £65 million to £75 million annually (1988: 1£ = $1.78).

Using Fatality Analysis Reporting System (FARS) data, Sullivan and Flannagan (*7*) investigated the pedestrian's risk in darkness. They examined pedestrian collisions as a function of dark–light conditions and vehicle speed and found that pedestrians were more at risk in dark than light conditions. Vehicle speed and visibility were presented as evidence for the increased risk of pedestrian collisions. To verify the effects of speed and visibility, Sullivan and Flannagan examined crash data before and after DST time was implemented for varying roadway types. Those authors suggested that pedestrians were at greater risk in darkness and even more so on roadways with higher speed because of drivers' inability to perform avoidance maneuvers successfully (*7*).

In a more recent study, Adams et al. investigated the safety effects of DST on collisions involving child pedestrians and found that operating BST year around would reduce the number of serious and fatal accidents involving children (*8*). Using sunrise and sunset tables in the United Kingdom, the authors determined the light conditions for each crash involving a child pedestrian. On the basis of this assessment, they concluded that changing to BST year around would prevent 15 serious or fatal accidents, a reduction of 0.5% (*8*). The authors reported that about 2,900 injuries involving children, of whom 743 were seriously injured, occurred between November 1988 and March 2003 in the United Kingdom.

In summary, previous research has shown that DST (and BST) influences the safety of road users, albeit that all studies have shown extremely small changes in absolute values. Some studies contained methodological limitations, including selection of an inadequate modeling framework and use of short-term results and their subsequent application over a longer term. It is hoped that the current research will extend previous work in this area by analyzing the safety effects in more details and with different statistical tools. The next section describes the data collection activities of the current work.

DATA COLLECTION

A total of 3 years of crash data were used in this study. The data were collected in nine districts in Texas: Bryan, Yoakum, Austin, Houston, Beaumont, Lufkin, Tyler, Dallas, and Waco. In the 3-year period from 1998 to 2000, 708,755 crashes, including severities of fatal (K), incapacitating (A), nonincapacitating (B), possible injury (C), and property damage only (PDO), were reported for all urban roads located in Texas (populations of 5,000+). Of these crashes, 157,290 were classified as KAB crashes. The crashes were then grouped for the morning period (5:00 a.m. to 10:00 a.m.) and the afternoon period (4:00 p.m. to 9:00 p.m.) by district for use in the analysis for quantifying the safety effects of DST.

In addition to crash data, sunrise and sunset information was collected from these districts to establish the amount of light for morning and afternoon 5-h periods. The U.S. Naval Observatory maintains a public website that provides yearly sunrise and sunset times for most locations around the United States (*9*). Data for 3 years of sunrise and sunset times were obtained and reduced for the nine districts' office locations. The calculated hours of daylight were averaged for all districts before they were included in the proposed models.

EXPLORATORY ANALYSIS

This section briefly describes the exploratory analyses conducted on the data. Monthly percentages of all Texas urban on- and off-system KAB crashes involving pedestrians and motor vehicles are presented in Figure 1. This figure shows an increase in the percentage of monthly pedestrian crashes for April and October for the 24-h period crash count. This result warranted further investigation for the 5-h morning and afternoon periods. April and October are the two months in which the time changes take place. For the morning period, an increase in the percentage of crashes can be seen starting in August. There may be some questions about the effects of DST in the fall as an increase in crashes can be seen starting the previous month. Other factors may play a role here, including the fact that the school year for most grades usually starts in late August. As Figure 2 shows, the hours of daylight in the morning and afternoon periods during the months before the change to DST increase at a higher rate in the afternoon than in the morning. This relationship could be related to the higher percentages of afternoon crashes in Figure 1. In contrast, the hours of daylight in the morning and afternoon periods begin to decrease before the time change to NST. Finally, an increasing trend in the number of morning and afternoon crashes can be seen in Figure 1 similar to the decrease in light in Figure 2.

If changing light conditions due to the onset of DST had any effect on pedestrian and motor vehicle crashes, that effect should be most noticeable in the morning and afternoon periods. Figure 2 shows the trend in the hours of daylight from sunrise and sunset for the morning period, 5:00 a.m. to 10:00 a.m., and the afternoon period, 4:00 p.m.

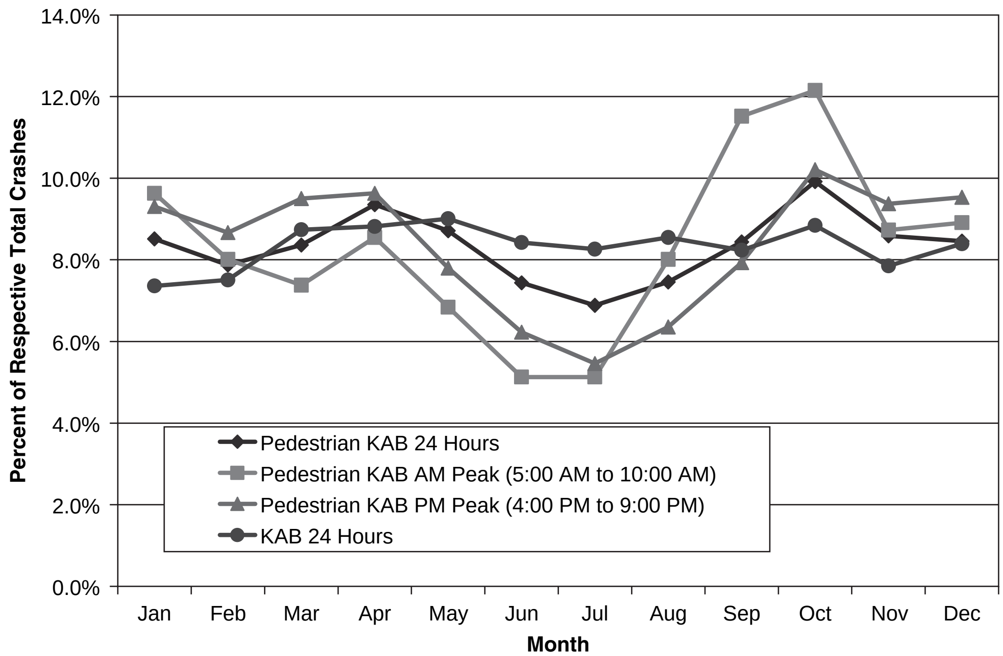

FIGURE 1 Texas urban on- and off-system KAB crash percentages by month (1998 to 2000).

to 9:00 p.m. As Figure 2 shows, additional light in the afternoon peak period results in less light in the morning peak period.

In summary, the exploratory analysis of the data revealed that pedestrian and motor vehicle crashes may have been influenced by both the onset and ending of DST and the varying amounts of daylight hours for morning and afternoon periods. The analyses carried out in the next sections try to clarify this relationship.

STATISTICAL ANALYSIS

To accomplish the first objective of this study, data were analyzed through a series of generalized linear models (GLMs) to establish a relationship between crashes occurring during the morning and afternoon periods, the amount of daylight, and seasons. Four models were produced: all KAB crashes during the morning period (5:00 a.m. to

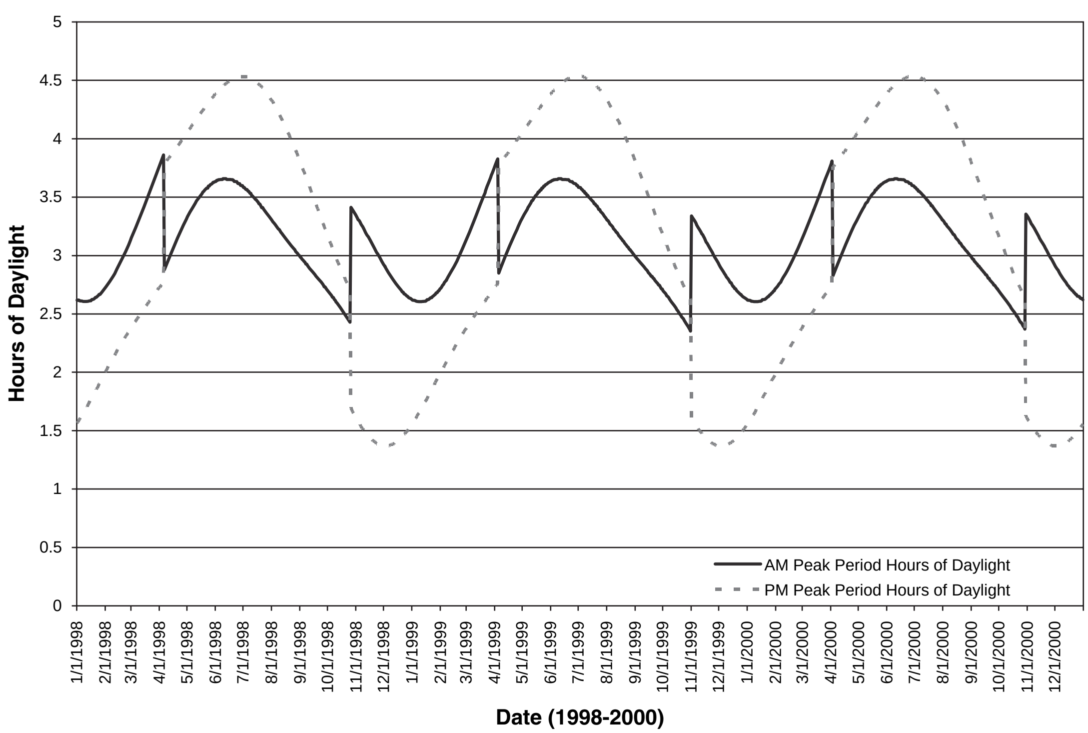

FIGURE 2 Hours of daylight in morning and afternoon 5-h periods (1998 to 2000).

10:00 a.m.); all KAB crashes during the afternoon period (4:00 p.m. to 9:00 p.m.); pedestrian KAB crashes during the morning period (5:00 a.m. to 10:00 a.m.); and pedestrian KAB crashes during the afternoon period (4:00 p.m. to 9:00 p.m.). The immediate safety effects to and from DST were estimated through a naïve before-and-after study and are explained further below.

Development and Application of Models

This section is divided into two parts. The first part covers model development, while the second describes the applications of the models for different types of hypothetical scenarios.

Model Development

As noted earlier, four statistical models were estimated. The four models were the following:

- All KAB crashes during the morning period,
- All KAB crashes during the afternoon period,
- Pedestrian KAB crashes during the morning period, and
- Pedestrian KAB crashes during the afternoon period.

The functional form selected for the models was the following:

$$\mu_i = b_0 e^{b_1 x_{1i} + b_2 x_{2i} + b_3 x_{3i} + b_4 x_{4i}} \quad (1)$$

where

μ_i = expected number of crashes for the 5-h period i (per day);
x_{1i} = the number of daylight hours within the 5-h period i;
x_{2i} = 1 if period i is located in winter, 0 if not;
x_{3i} = 1 if period i is located in spring, 0 if not;
x_{4i} = 1 if period i is located in summer, 0 if not; and,
b_0, b_1, b_2, b_3, b_4 = coefficients to be estimated.

The dummy variables above describing the seasons were used to capture in part exposure that may be influenced by the season. For instance, pedestrians are less likely to be present on the highway system during the summer months. Models using the month of the year were also evaluated but were eventually rejected. The coefficients for many models were nonsignificant. The functional form used in this work was very similar to the form used by Coate and Markowitz (*3*) and Ferguson et al. (*4*).

Previous studies have shown the Poisson–gamma (or negative binomial) models are more adequate to model crash data because these types of data often exhibit overdispersion or heterogeneity (*10*). From this assumption, the coefficients of the models were estimated through the use of the GENMOD procedure in SAS (*11*). Once the Poisson–gamma models were estimated, the fixed dispersion parameter α in $\mathrm{Var}(y) = \mu_i + \alpha\mu^2_i$ was evaluated to determine whether the variance was indeed greater than the mean. If the model's variance and mean were reasonably close, the model was refitted through use of the Poisson distribution (*12*). For two models, the Poisson distribution fitted the data more adequately. The characteristics of the input data for the models are shown in Table 1. The data in this table regroup the nine districts together.

Table 2 shows the relationship between motor vehicle and pedestrian crashes and the hours of daylight and season for the morning and afternoon periods, respectively. The relationships showed varying results. Some coefficients associated with a particular season were found not to be statistically significant at the .05 level (most were at the .10 level). Nonetheless, they were kept in the models because, in most cases, the season was associated either positively or negatively with motor vehicle and pedestrian crashes.

The results of the analysis show that motor vehicle crashes were negatively associated with the hours of daylight in the morning peak period, while the afternoon peak model showed a positive relationship to daylight hours. These relationships mean that, with additional light in the morning 5-h period, one would see a reduction in the number of crashes, while crashes would increase during the afternoon 5-h period with additional hours of daylight. The model output for the morning period fell in line with expected outcomes described earlier (*3, 4*). In contrast, however, the model output for the afternoon period showed a slight increase in the number of crashes with an increase in the hours of daylight. Some discrepancies with previous work could be explained with the types of data at hand. For example, the current research concentrated on the highest severity of each individual crash, whereas the majority of previous work examined the effects of DST on pedestrian and in-vehicle occupant fatalities. For both models, the winter and summer seasons

TABLE 1 Characteristics of KAB Crash Data Used for Developing Statistical Models

	Mean	Max.	Min.	Standard Deviation	Total
Daily 5-h a.m. period, motor vehicle crash counts	12.8	52	1	5.73	14,030
Daily 5-h a.m. period, pedestrian crash counts	0.55	5	0	0.81	600
Daily 5-h p.m. period, motor vehicle crash counts	24.19	58	7	6.83	26,515
Daily 5-h p.m. period, pedestrian crash counts	1.45	7	0	1.27	1,587
Hours of daylight during 5-hour a.m. period	3.11	3.86	2.35	0.37	—
Hours of daylight during 5-hour p.m. period	3.06	4.53	1.37	1.14	—

TABLE 2 Statistical Model Results: Motor Vehicle KAB Crashes

		Motor Vehicle KAB Crashes			Pedestrian KAB Crashes		
		Estimate	Standard Error	Log Likelihood	Estimate	Standard Error	Log Likelihood
a.m. 5-h period Poisson-gamma	Intercept $\ln(b_0)$	2.8845	0.1485	21,254.755†	3.1024	0.4649	−997.066†
	Daylight* b_1	−0.0913	0.0512	21,177.71	−0.5256	0.163	−977.20
	Winter* b_2	−0.0750	0.039		−0.1405	0.1125	
	Spring* b_3	−0.0544	0.0492		−0.0965	0.1552	
	Summer* b_4	−0.0797	0.0438		−0.2738	0.1393	
	Dispersion a	0.1221	0.0089		0.2917	0.0973	
p.m. 5-h period Poisson	Intercept $\ln(b_0)$	3.17040	0.0355	30,276.233†	2.3389	0.1092	−801.9562†
	Daylight* b_1	0.0169	0.0149	31,848.94	−0.1502	0.0481	−808.7262
	Winter* b_2	−0.1287	0.0241		−0.1434	0.0744	
	Spring* b_3	0.0128	0.0356		0.1263	0.1163	
	Summer* b_4	−0.0374	0.0383		−0.131	0.1303	

*Estimates with a negative sign represent a reduction in the number of crashes.
†Log likelihood with intercept only.

were associated with fewer crashes than the spring and fall seasons. Model outcomes imply that the fall season had the greatest effect on the number of crashes compared with the other seasons.

The output of the statistical model relating hours of daylight in the morning and the afternoon periods to motor vehicle crashes showed that pedestrian collisions were negatively associated with the hours of daylight and most notably the summer and fall seasons. This outcome agreed with many other studies on this topic; this suggests that an increase in daylight resulted in a decrease in the number of pedestrian crashes (*3, 4*).

Although the models developed in this work showed, in most cases, an appropriate relationship between crashes in daylight hours for the period located at the boundary delimiting night and day and season, there were some limitations that should be discussed. The first limitation is related to missing explanatory variables, including annual average daily traffic, weather patterns, and highway geometrics. It is true that these models may have contained few variables, but other existing models with very few variables, such as crash-flow models, have been well accepted by the research community. (Traffic flow in crash flow models is used as a proxy to capture all variation in crash.) Nonetheless, the authors understand that other variables should be included to capture better exposure and variables that may influence motor vehicle and pedestrian collisions during the morning and the afternoon periods. The second limitation is related to the format of the crash data. Crashes coded by the Department of Public Safety, the agency responsible for collecting crash data in Texas, represented only the highest severity of vehicle occupant injuries, unlike FARS. The last limitation is related to the fact that pedestrian crashes included in the Texas database represented only those in which a pedestrian was struck as the first harmful event and possibly did not represent all pedestrian–vehicular collisions. There is a possibility that the outcome of the pedestrian model could change with the influence of additional fatalities and injured pedestrians not collected in this study.

Applications of Models for Different Scenarios

This section describes the application of the models to three scenarios. The three scenarios were created to evaluate the model and predict potential safety effects of these changes to the duration of DST. With the assumption the models were properly estimated and applied to the following scenarios:

- Absence of DST [referred to as all normal standard time (ANST)],
- All DST, and
- Newly proposed DST by the U.S. Congress (labeled New DST).

Before the models were applied, it was important to show the changes in the number of daylight hours for the different scenarios (Table 3). This table shows that the change in hours of daylight between the morning and afternoon 5-h periods was greatest

TABLE 3 Amount of Light for DST Changes, 1998–2000

	A.M. Daylight (h)	A.M. Change* (h)	P.M. Daylight (h)	P.M. Change* (h)	A.M. Standard Deviation (h)	P.M. Standard Deviation (h)
Current	3404		3356		0.3697	1.138
All NST	4027	623	2733	−623	0.6880	0.7287
All DST	2931	−473	3829	473	0.6880	0.7287
New DST	3313	−91	3447	91	0.3761	1.1228

*Values with a negative sign represent a reduction in the hours of daylight.

for the year-round standard time scenario. As Table 3 shows, there were 623 additional hours of daylight in the morning peak period and 623 fewer hours of daylight in the afternoon peak period. The standard deviation of each time scenario was calculated over the 3 years of daylight data (the change was a little different for each district). The current time scenario had the lowest morning standard deviation, and the new scenario had the lowest afternoon standard deviation.

Table 4 shows the predicted number of KAB motor vehicle crashes during the DST duration changes. The amount of daylight per 5-h period was calculated for 1998 to 2000 by adding or subtracting 1 h, on the basis of start and end dates of each DST duration. For example, for the New DST starting on the second Sunday in March and ending on the first Sunday in November, 1 h would be added in the afternoon peak period and 1 h subtracted in the morning peak period for the New DST proposed by the U.S. Congress for the period of 1998 to 2000. The amount of daylight in each period was used in the models to predict the number of crashes for each scenario. As Table 4 shows, year-round standard time reduced the number of motor vehicular crashes by 952 over 3 years, a 2.35% decrease from the observed number of crashes during the morning and the afternoon periods. The same three scenarios were again used for predicting pedestrian crashes.

As can be seen in Table 4, the models predicted that year-round standard time would have little effect because only a reduction of one crash would be observed for crashes involving pedestrians. The crash reduction or increase for the morning and the afternoon periods canceled each other out. The All DST scenario predicted the lowest number of afternoon peak-period pedestrian crashes and had the largest gain in additional hours of daylight, 473, for all afternoon period scenarios (Table 4). Given the uncertainty associated with the predicted values estimated from the models, the comparison between the scenarios may not be statistically significant (*13, 14*). In addition, similar to the changes in all previous studies on this topic, the absolute changes in predicted values shown in this study were relatively small. Nonetheless, the information in Table 4 provides useful general trends.

Immediate Effects of DST

This section is divided into three parts. The first one describes the method used to determine the immediate effects of each time change. The second and third parts present the findings of the changes to and from DST, respectively.

Methodology

To find the immediate effect of changes in safety to and from DST, this study focused on the number of KAB motor vehicle and pedestrian crashes that occurred during the 5-day work week before and after the spring and fall time changes during the year for the morning and the afternoon periods respectively. The measures of effectiveness (MOEs) consisted of using a naïve before-and-after approach (*15*). Given the lack of appropriate exposure data, this method was the best tool available to conduct such study.

To complete the study, several parameters were calculated. Two of these were the count of crashes after a time change λ (Equation 2) and the expected number of crashes if nothing changed π (Equation 3) with the equations below (*15, 16*):

Count of crashes after:

$$\hat{\lambda} = \sum L(j) \tag{2}$$

Expected number of crashes if nothing changed:

$$\hat{\pi} = \sum K(j) \tag{3}$$

where the estimates of variance are

$$\mathrm{Var}\{\hat{\lambda}\} = \sum L(j) \tag{4}$$

$$\mathrm{Var}\{\hat{\pi}\} = \sum K(j) \tag{5}$$

In addition to these parameters, MOEs included the change in crashes $\hat{\delta}$, its variance $\mathrm{Var}\{\hat{\delta}\}$, the index of effectiveness $\hat{\theta}$, and its variance $\mathrm{Var}\{\hat{\theta}\}$. These MOE expressions are described by Equations 6 through 9.

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} \tag{6}$$

$$\mathrm{Var}\{\hat{\delta}\} = \mathrm{Var}\{\hat{\pi}\} + \mathrm{Var}\{\hat{\lambda}\} \tag{7}$$

$$\hat{\theta} = \frac{\hat{\lambda}/\hat{\pi}}{\left(1 + \mathrm{Var}\{\hat{\pi}\}/\hat{\pi}^2\right)} \quad \leftarrow \text{adjustment factor for less than 500 observations} \tag{8}$$

$$\mathrm{Var}\{\hat{\theta}\} \approx \frac{\theta^2\left[\left(\mathrm{Var}\{\hat{\pi}\}/\lambda^2\right) + \left(\mathrm{Var}\{\hat{\pi}\}/\hat{\pi}^2\right)\right]}{\left[1 + \mathrm{Var}\{\hat{\pi}\}/\hat{\pi}^2\right]^2} \quad \leftarrow \text{adjustment factor for less than 500 observations} \tag{9}$$

In addition to the before-and-after study, 95% confidence intervals were calculated for each MOE.

TABLE 4 Estimated Number of Crashes for DST Changes, 1998–2000

Crash Type	Scenario	A.M. Peak	P.M. Peak	Total	Total Change*	% Change
Motor vehicle KAB crashes	Current	14,036	26,520	40,556		
	All NST	13,347	26,257	39,604	–952	–2.35%
	All DST	14,623	26,704	41,327	771	1.90%
	New DST	14,143	26,557	40,700	144	0.36%
Pedestrian KAB crashes	Current	602	1,585	2,187		
	All NST	471	1,715	2,186	–1	–0.05%
	All DST	796	1,476	2,272	85	3.89%
	New DST	630	1,564	2,194	7	0.32%

*Estimates with a negative sign represent a reduction in the number of crashes.

Change to DST

Tables 5 and 6 present the findings of the before-and-after study for the change to DST. For this change, 1 h of daylight was added in the afternoon and 1 h was removed in the morning.

Table 5 shows a 4.5% increase (101 crashes) in motor vehicle crashes for the week following the change to DST (i.e., for 5 entire days). In addition to this finding, a 6% reduction in fatal accidents was observed, similar to the reductions of previous studies by Coate and Morkowitz (*3*), Ferguson et al. (*4*), and Sullivan and Flannagan (*7*). The changes were not found to be significant. Although the snapshot of data for all crashes did not produce findings similar to those of previous studies, those studies mainly focused on in-vehicle occupant and pedestrian fatalities. Perhaps the short-term effects were dependent on crash severity during the time period under study. However, it is possible that a small peak would be observed immediately following the change, but the number of crashes would become lower as the time period after the change increased, as shown with the coefficients of the models described above and the general trend illustrated in Figure 1.

Table 6 shows that crashes involving pedestrians were reduced by 8.5% (12 crashes) the week following the change to DST. In addition, a 37% reduction, or 5 crashes, in pedestrian fatalities was observed. As above, the changes were not found to be significant.

Change to NST

Tables 7 and 8 show the results for the change in crash counts from DST to NST. For this change, an hour of daylight was added in the morning period and an hour was removed in the afternoon period. For this change, an increase in the number of crashes was observed for both morning and afternoon time periods and met the expected outcome documented in previous studies.

Table 7 shows a significant increase, with 138 additional crashes (7%) occurring the week following the change to NST time. The morning period experienced 57 additional crashes, a 14% increase. Motor vehicle crashes involving at least one fatality increased by 17%, or 7 crashes, but this increase was not found to be statistically significant.

Table 8 also shows a significant increase in crashes. A total of 34 additional pedestrians were struck and injured during the week following the change to NST. Both morning and afternoon 5-h periods experienced an increase in crashes involving pedestrians. The findings were also found not to be statistically significant.

CONCLUSIONS AND RECOMMENDATIONS

This study has examined the safety effects of DST on the number of KAB crashes for nine districts in Texas. The study used an exploratory analysis, statistical modeling, and a before-and-after study. The output of the statistical models showed that motor vehicle crashes decreased with increasing daylight in the morning period (5:00 a.m. to 10:00 a.m.), while they increased with increasing daylight during the afternoon period (4:00 p.m. to 9:00 p.m.). The output of pedestrian models suggested that crashes decreased during the same morning and afternoon periods with increasing hours of daylight. Model predictions showed that year-round NST would reduce motor vehicle crashes by 952 (2.35%) and would have limited effects for pedestrian crashes over 3 years (at the boundary delimiting daylight and dark conditions). The reduction and increase canceled each other out for the periods under study. The reduction in motor vehicle collisions was attributed to the overall increase in daylight hours during the morning and afternoon periods for the entire year. It was also apparent by way of the naïve before-and-after study that there were immediate effects, usually negative, associated with the changes to and from DST. This was especially true for the change in October from DST to NST, with a significant increase in motor vehicular and pedestrian crashes. Similar to the results of the model, crashes involving pedestrians seemed to be influenced by the daylight hours. This outcome was consistent with previous research on this subject. The number of fatal pedestrian crashes decreased when the change to DST occurred, although it was found not to be statistically significant, and increased when the change to NST occurred. The outcome of this study showed that DST and light conditions were associated with the risk of motor vehicle and pedestrian crashes. However, as all previous studies on the safety effects of DST, the absolute changes estimated in this work are extremely small (<2.5%). The models developed in this work were applicable only to the nine

TABLE 5 Before–After Results for Change to DST: Motor Vehicle KAB Crashes

Change to DST All KAB Crashes Week	Sum $K(j)$ (Before)	Sum $L(j)$ (After)	Change	Theta	STDV $\{K(j)\}$	STDV $\{L(j)\}$	STDV $\{K(j) - L(j)\}$	STDV {Theta}	Confidence 95%	Significance
Total accidents (5 × 24-hour)	2257	2358	−101	1.04	47.51	48.56	67.19	0.03	131.69	No
Peak periods										
a.m. 5-h period	414	405	9	0.98	20.35	20.12	28.62	0.07	56.09	No
p.m. 5-h period	774	843	−69	1.09	27.82	29.03	40.21	0.05	78.82	No
Severity										
Nonincapacitating	1737	1843	−106	1.06	41.68	42.93	58.94	0.04	115.52	No
Incapacitation	453	452	1	1.00	21.28	21.26	30.10	0.07	59.00	No
Fatal	67	63	4	0.94	8.19	7.94	11.58	0.17	22.69	No

*Estimates with a negative sign represent an increase in the number of crashes.

TABLE 6 Before–After Results for Change to DST: Pedestrian KAB Crashes

Change to DST Pedestrian KAB Crashes Week	Sum $K(j)$ (Before)	Sum $L(j)$ (After)	Change	Theta	STDV $\{K(j)\}$	STDV $\{L(j)\}$	STDV $\{K(j) - L(j)\}$	STDV {Theta}	Confidence 95%	Significance
Total accidents (5 × 24-h)	140	128	12	0.91	11.83	11.31	16.73	0.11	32.80	No
Peak periods										
a.m. 5-h period	16	19	–3	1.19	4.00	4.36	5.92	0.40	11.60	No
p.m. 5-h period	62	50	12	0.81	7.87	7.07	10.58	0.15	20.74	No
Severity										
Nonincapacitating	78	80	–2	1.01	8.83	8.94	12.49	0.16	24.48	No
Incapacitation	47	38	9	0.79	6.86	6.16	9.70	0.17	19.00	No
Fatal	15	10	5	0.63	3.87	3.16	5.48	0.26	10.74	No

*Estimates with a negative sign represent an increase in the number of crashes.

TABLE 7 Before–After Results for Change to NST: Motor Vehicle KAB Crashes

Change to STD KAB Crashes Week	Sum $K(j)$ (Before)	Sum $L(j)$ (After)	Change	Theta	STDV $\{K(j)\}$	STDV $\{L(j)\}$	STDV $\{K(j) - L(j)\}$	STDV {Theta}	Confidence 95%	Significance
Total accidents (5 × 24-h)	2030	2168	–138	1.07	45.06	46.56	63.72	0.03	124.89	Yes
Time of day										
a.m. 5-h period	397	454	–57	1.14	19.92	21.31	29.17	0.08	57.18	No
p.m. 5-h period	657	711	–54	1.08	25.63	26.66	36.99	0.06	72.49	No
Severity										
Nonincapacitating	1591	1718	–127	1.08	39.89	41.45	56.41	0.04	110.56	Yes
Incapacitation	397	401	–4	1.01	19.92	20.02	28.18	0.07	55.23	No
Fatal	42	49	–7	1.17	6.48	7.00	9.17	0.25	17.96	No

*Estimates with a negative sign represent an increase in the number of crashes.

TABLE 8 Before–After Results for Change to NST: Pedestrian KAB Crashes

Change to STD Pedestrian KAB Crashes Week	Sum $K(j)$ (Before)	Sum $L(j)$ (After)	Change	Theta	STDV $\{K(j)\}$	STDV $\{L(j)\}$	STDV $\{K(j) - L(j)\}$	STDV {Theta}	Confidence 95%	Significance
Total accidents (5 × 24-h)	114	148	–34	1.29	10.68	12.17	15.10	0.16	29.60	Yes
Time of day										
a.m. 5-h period	19	26	–7	1.37	4.36	5.10	6.71	0.41	13.15	No
p.m. 5-h period	50	60	–10	1.20	7.07	7.75	10.49	0.23	20.56	No
Severity										
Nonincapacitating	70	99	–29	1.39	8.37	9.95	11.83	0.22	23.19	Yes
Incapacitation	38	36	2	0.92	6.16	6.00	8.72	0.21	17.09	No
Fatal	6	13	–7	1.86	2.45	3.61	3.46	0.92	6.79	Yes

*Estimates with a negative sign represent an increase in the number of crashes.

districts from which the data were extracted. Thus, these models should not be used outside the geographical areas defined herein.

Although prediction of the models showed reductions in the number of pedestrian collisions as a function of daylight hours for the morning and the afternoon periods, additional research is needed to include other explanatory variables that may influence pedestrian crashes, such as pedestrian volumes (to capture exposure better) and the presence of sidewalks or other types of accommodations. One way to accomplish this would be to use a more statistically robust study, such as the empirical Bayesian method to account for the RTM and site selection biases, where appropriate. Weather patterns should also be included over the study period to capture any trends influencing traveling patterns and driving (or walking) behavior of road users. In establishing the immediate effects of changes to and from DST, exposure variables should also be included as part of the before-and-after analysis. In addition to these, it could be beneficial to complete a cost–benefit analysis for all injury accidents, with appropriate crash costs. Finally, one should examine how the sudden change in time affects important human factors characteristics (e.g., changes in sleep patterns) of drivers and pedestrians.

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