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The Iowa graduated driver licensing program: Effectiveness in reducing crashes of teenage drivers

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Abstract

Problem: Graduated Driver Licensing (GDL) programs vary in the United States in terms of implementation and restrictions. The State of Iowa's GDL program is assessed for its effectiveness in reducing crashes among teenage drivers. *Method:* Time series analysis was used to evaluate police documented crashes involving 16-, 17-, and 18-year-old drivers over a 10 year period, with an intervention identified at the point of GDL implementation. *Results:* After controlling for seasonal trends and auto-correlative effects, a significant reduction in the crash rate of and 16- and 17-year-old drivers was observed due to the GDL implementation. However, there were no significant reductions in crash rates for 18-year-old drivers. *Discussion:* The analyses suggest that the Iowa GDL program is effective in reducing the crash rates of 16- and 17-year-old drivers but the effects do not sustain for 18-year-old drivers. *Impact on Industry:* The results suggest that the program appears to be working, however further analysis is needed to determine what factors are preventing lasting effects for these teenage drivers.

Keywords: Teenagers; intervention analysis; young drivers; crash rates; ARIMA model; time-series analysis

1. Introduction

Graduated Driver Licensing (GDL) programs have been implemented in almost every state in the United States as a mechanism to reduce the crashes associated with teenage drivers (Insurance Institute of Highway Safety [IIHS], 2006). These programs are also viewed as an effort to resolve the 'licensure paradox' that inexperienced drivers need more experience, but more exposure tends to increase crash likelihood (Simons-Morton, 2002). The major goal of such programs is to allow novice drivers to gain experience in less risky driving situations and then gradually move toward full licensure (IIHS, 2006). Dee, Grabowski, and Morrisey (2005) estimated that an additional 131 teenage crash fatalities would occur per year if the GDL programs in the 38 states investigated had not been implemented (as of 2002). There is, however, a concern that the number of restrictions placed on novice drivers, as part of GDL, may limit opportunities to gain experience in high risk situations (McKnight & Peck, 2002). Alternatively, a GDL program may not actually influence risk taking behaviors, it just disallows certain hazardous situations (Ferguson, 2003).

Numerous studies have evaluated the effectiveness of GDLs in terms of what driving factors should be restricted, and what types of assistance should be provided to teenage drivers (Begg, Stephenson, Alsop, & Langley, 2001; Dee et al., 2005; Ferguson, 2003; Mayhew, Simpson, Groseilliers, & Williams, 2001; Mayhew, Simpson, & Pak, 2003; Morrisey, Grabowski, Dee, & Campbell, 2006; Simpson, 2003; Ulmer, Preusser, Williams, Ferguson, & Farmer, 2000; Williams & Ferguson, 2002; Williams, Nelson, & Leaf, 2002). Dee et al. (2005) suggested more stringent GDL programs to effectively reduce crashes for teenage drivers. Others have proposed parent or guardian involvement, an important but rarely examined component of the GDLs (Shope & Molnar, 2003). Regardless, there is a growing consensus that GDL programs are effective in reducing the crashes for drivers that participate (McKnight & Peck, 2002). However, some studies do not show a lasting effect for the drivers after they graduate (Mayhew et al., 2003). Ulmer et al. (2000) found that the graduated licensing program in Florida significantly reduced the crash rates for drivers

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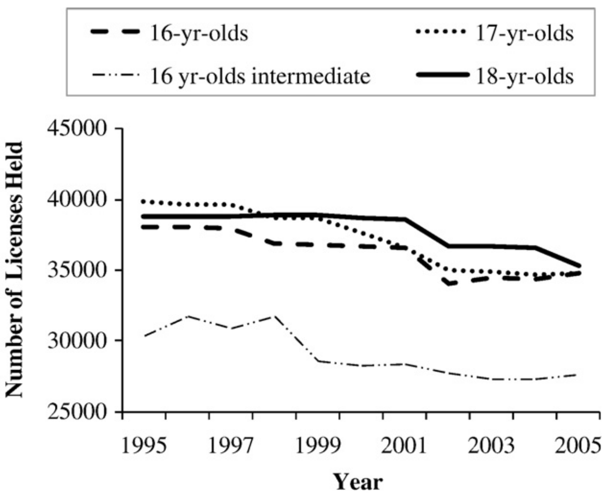

Fig. 1. Annual number of licenses for 16-, 17-, and 18-year-olds in Iowa.

between the ages of 15 and 17 year-olds, but the crash rates of 18 year-olds were not significantly reduced. These results would indicate that the GDL programs are successful in reducing crash risks while teenage drivers are enrolled in the program but return to levels similar to those prior to the program implementation (Agent et al., 2001).

Chen, Baker, and Guohua (2006) have shown that varying program restrictions may influence the effectiveness in reducing the fatal crash rate involvement for 16-year-old drivers. The different levels of effectiveness and varying program restrictions suggest that more research is needed to understand why some programs (or specific program components) may be more effective than others. It should be noted that many of the studies that evaluated GDL programs have examined crash rates (or alternatively crash frequency, number of fatalities or injuries, etc.) as normally and independently, samples over time. However, there are numerous time-varying exogenous variables that impact traffic safety conditions such as seasonal changes, advancements in safety technology, and population changes over time. Regardless of the effect, these changes over time should be taken into consideration in evaluating the GDL's effectiveness, or the conclusions may be misleading.

The implementation of GDL programs vary among states (Hedlund, Shults, & Compton, 2003). They can include restrictions in driving time, number of passengers, and even the use of cellular phones and other distracting devices. In general, these programs have been shown to be effective in reducing the injuries sustained by teenage drivers (Hedlund et al., 2003). Many of the states whose GDL programs have been evaluated include Florida, Michigan, California, Ohio, and Pennsylvania (Hedlund & Compton, 2005). The State of Iowa implemented a GDL program in January 1999 and was 1 of 17 states that implemented a GDL program before 2000 (Shope & Molnar, 2003). Iowa's program requires a minimum of 20 hours supervised driving followed by a 12-month intermediate license period with night time (12:30 a.m. to 5:30 a.m.) and passenger restrictions based on the number of available seatbelts. The intermediate period is only available after the teenager has turned 16. Full licensure can then only be obtained by successful completion of the intermediate period with no traffic violations (17-years-old at the earliest).

One confounding factor associated with the success of the GDL in Iowa is that it is one of a few states that maintain a Minor School Licensing (MSL) program. Within Iowa's MSL program and prior to the GDL program, 14.5 year-old-drivers are allowed to drive after they complete the driver's education class, a knowledge test, and a driving test. They are limited to driving to and from school and after school activities. Another similar program is the "To and From School License" in Nevada (DMVNV, 2006). These teenagers may have more experience compared to teenagers in other states or those who do not participate in the program. The existence of the school license in Iowa suggests that these teenage drivers may differ from those teenagers enrolled in GDL programs in other states. There are two major objectives of this study: (a) to assess whether Iowa's GDL program is effective while the driver is in the program and (b) to assess whether or not the effects are lasting even a year after program completion.

The studies cited thus far would suggest that the implementation of the Iowa GDL program would significantly impact the crash rates of 16- and 17-year-old drivers. It is also hypothesized that a lasting effect may not be observed after the

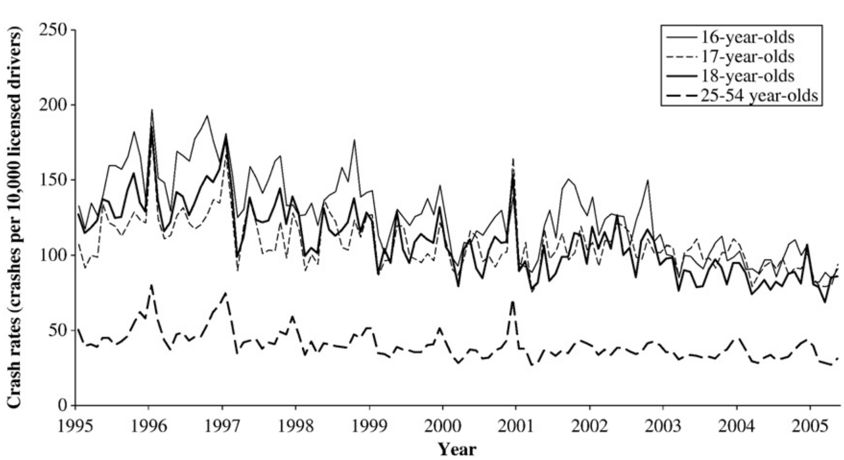

Fig. 2. The crash rates per month for teenage drivers (16-, 17-, and 18-year-old), and low crash risk drivers (25-54 years-old) in Iowa per 10,000 licensed drivers.

program ends, potentially because of delayed licensure. Within the Iowa program, drivers who have reached the age of 17 and have completed one year in the intermediate phase without any citations are then able to obtain a full driver's license. These same drivers are therefore evaluated at age 18 to evaluate the presence of lasting effects that may result from being a participant in the GDL program.

2. Method

Crash data from 1995 to 2005 are available as part of the Iowa Department of Transportation's SAVER (Safety, Analysis, Visualization, and Exploration Resource) program. This database includes crash and vehicle characteristics, driver and passenger demographics and injury severity, as well as contributing factors for all the police documented crashes in Iowa. Data from the Iowa DOT's yearly licensure snapshot are also used to establish rates for this analysis. The licensure snapshots document the number of active licenses awarded by the DOT to Iowans and is segmented by driver age. For teenage drivers, the number of licenses refers to the number of valid learner's permits or intermediate (provisional) driver's licenses during that year. Separate intervention time series analyses were conducted for 16- and 17-year-old drivers as well as for 18-year-old drivers. As a means to control for exposure, other studies have used an estimated value for the teenage miles driven or a total population count (Agent et al., 2001; Masten & Hagge, 2004; Shope & Molnar, 2004). These analyses may be

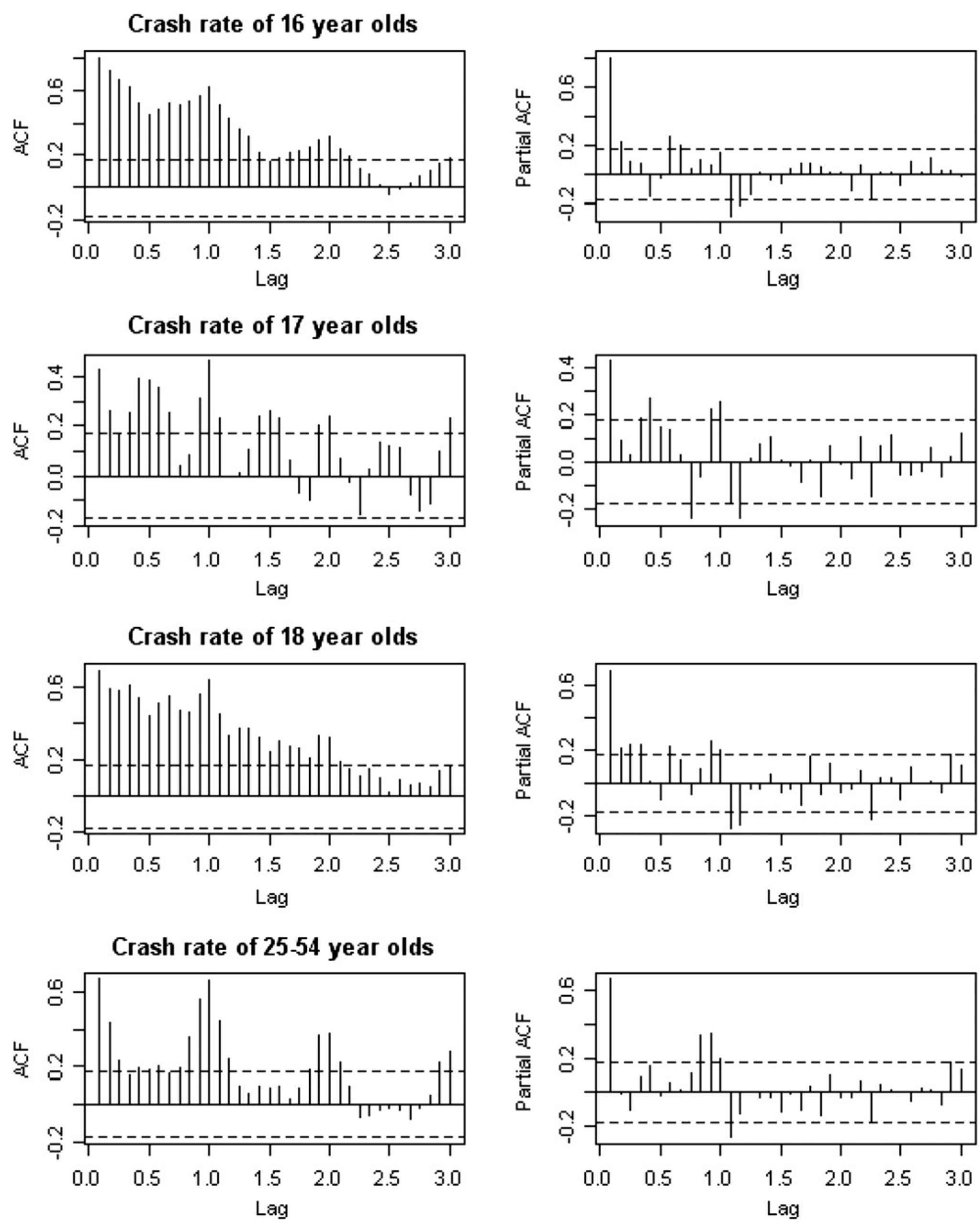

Fig. 3. The autocorrelation (ACF) and partial autocorrelation (PACF) function plots for the crash rates of all four age groups. Note. Lag 1 corresponds to 12 months.

affected by individuals postponing licensure until they are 18 (they would avoid participating in the GDL programs, which is also referred to as delayed licensure) and the non-driving populations who were not exposed to the intervention. The analyses in this study examined the crash rates (i.e., crash frequency divided by the number of valid driver's licenses outstanding for that age group for that year) for each month before and after implementation of the GDL on January 1999.

A total of 126 months of data are used in this analysis (only the first five months of crash data during 2005 were available at the time of the analysis). The crash rate for a low risk age group (25–54 year-olds) is used as a covariate to reduce biases in the model based on changes in population and other factors (e.g., unobserved effects from weather, traffic) that may impact the number of crashes and is similar to the 25–54-year-olds used by Masten and Hagge (2004). The crash rate for the low risk age group was also computed as the crash frequency divided by the number of licensed drivers each month. The implementation of the GDL program in Iowa (January 1999) is the intervention date for the 16-year-old driver time series model. For the 17- and 18-year-old drivers, the GDL intervention corresponded to one and two years after program implementation (January 2000 and January 2001, respectively). These intervention times correspond to the first set of 17-year-olds who would have completed the GDL program, and then when these teenage drivers became 18 years of age. Intervention time series analysis has been used by other researchers to evaluate the GDL programs in other states and provinces, and has been discussed as one of the most appropriate analysis methods for evaluating the effectiveness of these programs (Masten & Hagge, 2004; Mayhew et al., 2001; McKnight & Peck, 2002). If the correlations between observations are not taken into account (i.e., crash rates are treated as independent observations), the validity of the statistical results would be questionable.

In order to examine the effectiveness of the Iowa GDL, an intervention time series analysis was conducted using the statistical software R, specifically the Autoregressive Integrated Moving Average (ARIMA) function within the Stats package. An intervention time series analysis allows one to examine system-wide changes in a time-based data series while accounting for seasonal trends as well as factors associated with an intervention (for a more complete review see McDowall, McCleary, Meidinger, & Hay (1980)). Each teenager model was initially examined as a single time series with the GDL as the intervention. That is, the initial models did not include the covariate for the 25-54-year-old crashes per 10,000 licensed drivers. Additional regression parameters were then included (outliers and covariate) in the model to account for other sources of variance in the observations (Riise & Tjøsteim, 1984; Wei, 1990).

3. Results

The number of licenses awarded to 16-, 17-, and 18-year-olds in Iowa is shown in Fig. 1. The proportion of 16-year-olds with intermediate (or provisional) licenses is available from 1995 to 2005. However, the distinction between those who participated in the GDL program and those who did not is not available. Therefore, the year 1999 can include 16-year-olds who are and are not in the GDL program. After 1999, all 16-year-olds who had an intermediate license were required to participate in the program. Further, data that distinguishes between the MSL and moped or instructional permits are only available for the most recent analyzed year, 2005. In 2005, the MSL licensures represented only 5.7% (1,091) of all of the license types for drivers 14-years-old or younger (n = 17,940) with 94.2% representing instructional permits. Because these subdivided data were not collected prior to 2005, it was not possible to examine their overall impact on the Iowa GDL program. As shown in Fig. 1, there is a general reduction in the number of licenses acquired for the teenage drivers that is taken into account as part of the dependent measure (crash frequency over the number of licensed drivers). The percentage of intermediate licenses per year for 16-year-old drivers ranges

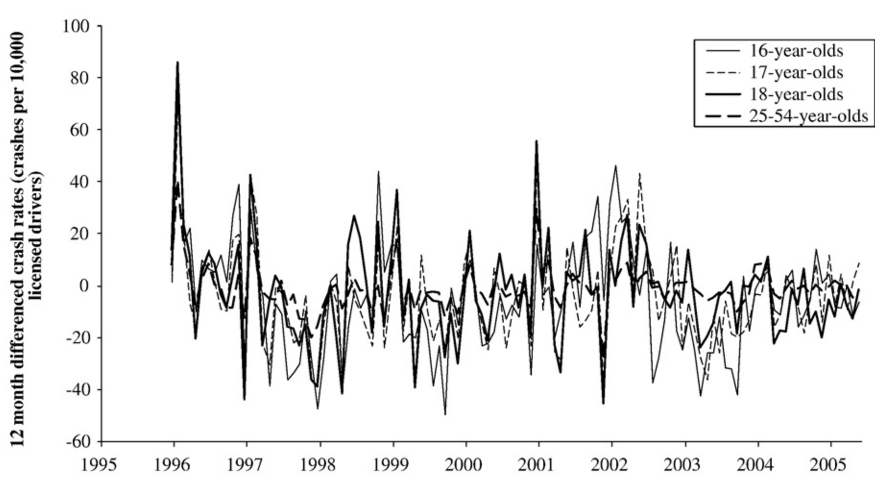

Fig. 4. Seasonally differenced (by 12 months) crash rates for teenage drivers (16-, 17-, and 18-year-old), and low crash risk drivers (25-54 years-old) in Iowa per 10,000 licensed drivers.

from 77.7% to 83.8% of the total number of licenses issued before the implementation of the GDL and from 77.0% to 80.0% after the implementation of the GDL, suggesting a fairly consistent percentage over time.

A decreasing crash rate was observed from January 1995 to June 2005 for all drivers examined (16-, 17-, and 18-years-old, and 25-54 year-old drivers; Fig. 2). The crash rates also follow a cyclical pattern that is evident in the autocorrelation plots shown in Fig. 3. Due to these effects, a seasonal difference (s = 12) was taken for each age group. Figs. 4 and 5 show the time series and autocorrelation plots for the differenced series for the crash rates of all four age groups. The differenced series are stationary as indicated by the time series plots and Dickey-Fuller tests (Dickey, Bell, & Miller, 1986). There is a significant autocorrelation at seasonal lag 1, and partial autocorrelation at seasonal lags 1 and 2 suggesting a seasonal moving average (SMA) term. There are also significant autocorrelations and partial autocorrelations for non-seasonal lags, indicating a possible non-seasonal autoregressive (AR) and/or moving average (MA) component for the models. The effect of GDL is modeled as a permanent step change.

After modeling each time series (i.e., teenage and middle-age drivers crash rates), the crash rate of 25–54 year-old drivers was also included as a covariate in the teenage driver time-series models to account for trends that may not be captured by ARIMA modeling. Because seasonal differencing was used in

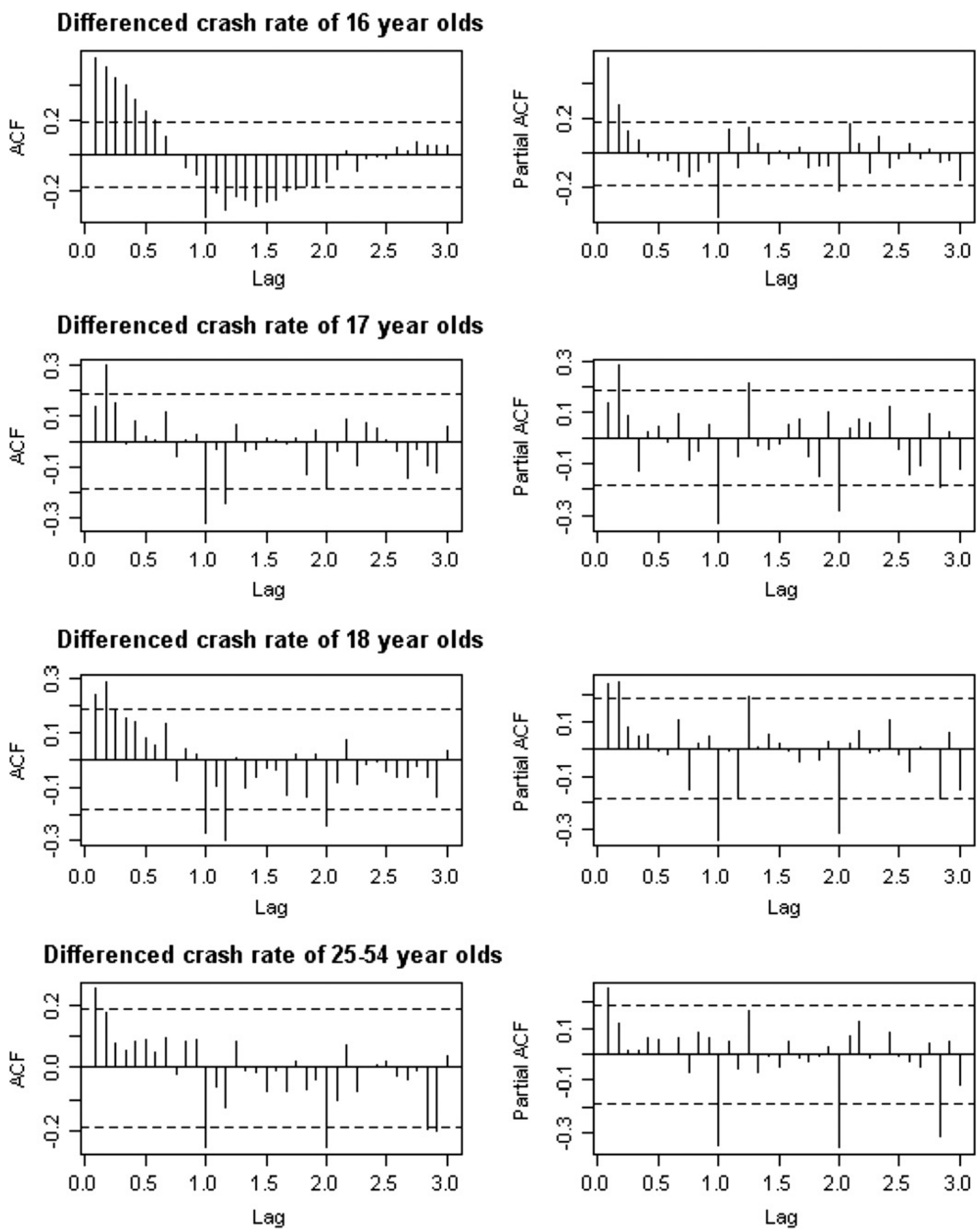

Fig. 5. The autocorrelation (ACF) and partial autocorrelation (PACF) function plots for the seasonally differenced crash rates of all four age groups.

the analysis of 16-, 17-, and 18-year-old driver crash rates, the covariate series was also seasonally differenced (shown in Fig. 3). In order to avoid spurious correlation, pre-whitening of the covariate and each dependent (i.e., seasonally differenced crash rates of 16-, 17-, 18-year-old drivers) series was performed. The cross-correlation functions were significant at lags 0 and −12 (seasonal lag 1) and therefore needed to be included in the initial models. The lagged (−12) covariate series were not found to be significant in any of these models and were therefore not considered hereafter.

For each model, diagnostic checks were performed to investigate the validity of model assumptions, such as inspection of residual plots, Ljung-Box tests for the independence of residuals, and tests for both additive and innovative outliers. If an additive outlier was detected, it was included in the model as an explanatory variable. The best fit and the most parsimonious model that satisfied model assumptions was selected based on the model diagnostic checks as well as the Akaike Information Criterion or AIC (Akaike, 1979). The models for the three teenager groups resulted in lower AIC values with the inclusion of the covariate time series.

3.1. Covariate: Crashes of 25-54 Year-Old Drivers

In order to ensure that the 25−54 year-old drivers are an appropriate covariate for the crashes of teenage drivers, an ARIMA model was constructed to examine the relationship between this age group and the GDL intervention. The model for the 25-54 year-old drivers' crashes is presented in Eq. (1) and as expected, GDL intervention was not significant (Table 1). Thus, all subsequent models include this covariate.

$$y_t - y_{t-12} = \mu + \phi(y_{t-1} - y_{t-13}) + e_t - \Theta e_{t-12} + GDL \qquad (1)$$

3.2. Crashes of 16-Year-Old Drivers

Different models were fitted for this time series (Table 2). As expected from the autocorrelation function plots described earlier, the models included autoregressive (AR(1)), moving average (MA(1)), and seasonal moving average (SMA(1)) terms. The first two models reported in Table 1 do not include the covariate time series. Model 2 was obtained by dropping the insignificant intercept term from Model 1. The next two models (Models 3 [with intercept] and 4 [no intercept]) include the covariate time series and are better fits to the data as indicated by smaller AIC values. Model 4 has the smallest AIC value, and hence provides the best fit to the data. The form for Model 4 is:

$$y_t - y_{t-12} = \phi(y_{t-1} - y_{t-13}) + e_t - \theta e_{t-1} - \Theta e_{t-12} + GDL + LRAG \qquad (2)$$

where the GDL is the intervention variable and the LRAG is the seasonally differenced covariate crash rate for the low risk age group. According to this model GDL has a significant impact on the seasonally differenced crash rates of 16-year-old drivers. Controlling for other covariates, the GDL implementation is associated with a reduction of 5.58 crashes (95% CI: 2.07, 9.09) per 10,000 licensed 16-year-old drivers per month. From 1995 to 2005, the average annual number of licenses in Iowa for 16-year-old drivers was 36,338. Therefore, the estimated effect of GDL approximates to 243 crashes reduced per year.

3.3. Crashes of 17- and 18- Year-Old Drivers

The intervention time series analysis for the 17- and 18-year-old drivers' crashes includes several components similar to the 16-year-old model. The models generated for the 17- and 18-year-old drivers' crash rates are shown in Tables 3 and 4,

Table 1
Coefficient estimates (and standard error) for the model predicting crashes per 10,000 licensed 25-54 year-olds (seasonally differenced time series)

Variable		Coefficient estimate (standard error)
AR1	ϕ	0.30 (0.10)*
SMA1	Θ	−1.00 (0.11)*
Intercept	μ	−2.19 (0.71)*
GDL (step input)		0.83 (0.91)
Outlier 1		−15.13 (3.12)*
AIC		707.58

Notes. * indicates statistical significance at p<0.05; AR1: Autoregressive 1, SMA1: Seasonal moving average 1. GDL: Graduated Driver Licensing program, AIC: Akaike Information Criterion.

Table 2
Coefficient estimates (and standard error) for four models predicting crashes per 10,000 licensed 16-year-old drivers (seasonally differenced time series)

Variable		Model 1	Model 2	Model 3	Model 4
AR1	ϕ	0.94 (0.04)*	0.93 (0.04)*	0.87 (0.07)*	0.86 (0.07)*
MA1	θ	−0.56 (0.08)*	−0.58 (0.08)*	−0.42 (0.11)*	−0.41 (0.11)*
SMA1	Θ	−0.77 (0.10)*	−0.69 (0.1)*	−0.68 (0.10)*	−0.68 (0.10)*
Intercept	μ	3.68 (5.84)		1.04 (3.46)	
GDL (step input)		−12.61 (6.95)	−8.82 (2.97)*	−6.76 (4.34)	−5.58 (1.79)*
LRAG (lag 0)				1.47 (0.15)*	1.47 (0.15)*
Outlier 1			25.51 (12.82)*		
AIC		901.54	898.07	836.96	835.05

Notes. * indicates statistical significance at p<0.05; MA1: Moving average 1, LRAG: seasonally differenced covariate crash rate for Low Risk Age Group, all other abbreviations previously defined.

Table 3
Coefficient estimates (and standard error) for three models predicting crashes per 10,000 licensed 17-year-old drivers (seasonally differenced time series)

Variable		Model 1	Model 2	Model 3
AR1	ϕ	0.89 (0.10)*	0.94 (0.05)*	0.84 (0.16)*
MA1	θ	−0.79 (0.12)*	−0.79 (0.08)*	−0.67 (0.22)*
SMA1	Θ	−1 (0.13)*	−1 (0.14)*	−0.76 (0.10)*
Intercept	μ	−2.43 (1.41)		2.35 (1.01)*
GDL (step input)		−0.56 (2.14)	−3.88 (1.19)*	−3.22 (1.43)*
LRAG (lag 0)				1.99 (0.12)*
Outlier 1		−49.37 (7.90)*	−48.06 (7.87)*	
Outlier 2		62.28 (12.71)*	58.00 (12.46)*	
AIC		883.35	883.33	774.85

Note: * indicates statistical significance at p<0.05.

Table 4
Coefficient estimates (and standard error) for three models predicting crashes per 10,000 licensed 18-year-old drivers (seasonally differenced time series)

Variable		Model 1	Model 2	Model 3
AR1	ϕ	0.87 (0.1)*	1.00 (0.0009)*	0.78 (0.12)*
MA1	θ	−0.73 (0.12)*	−0.80 (0.06)*	−0.56 (0.15)*
SMA1	Θ	−1.00 (0.26)*	−0.96 (0.19)*	−0.69 (0.13)*
Intercept	μ	−6.40 (1.13)		−2.15 (0.98)*
GDL (step input)		2.04 (2.09)	2.97 (3.90)	−0.74 (1.65)
LRAG (lag 0)				1.86 (0.13)
Outlier 1		−45.75 (7.74)*	−45.68 (7.81)*	
Outlier 2		57.22 (12.40)*	54.51 (12.54)*	
AIC		883.02	887.51	797.01

Note: * indicates statistical significance at $p<0.05$.

respectively. For both time series the third model had the smallest AIC value and provided the best fit to the data. The GDL intervention had a significant effect for 17-year-old drivers but not for 18-year-old drivers.

4. Discussion

The crash risks of teenage drivers remain relatively high compared to other age groups even with the implementation of GDL programs (Ferguson, 2003). The results of this study provide further support for the implementation and continuation of these programs. In Iowa, the GDL program has significantly reduced 16- and 17-year-old drivers' crash rates. However, the GDL program does not appear to significantly reduce the crash rates for 18-year-old drivers which supports the original hypothesis that there may not be a lasting effect from this program. This outcome may be related to the secondary effect of delay licensure. More specifically, teenagers are choosing to wait until they are 18-years-old to obtain a full drivers license in order to avoid participation in the GDL program (Shope, Molnar, Elliott, & Waller, 2001; Masten & Hagge, 2004; Ulmer et al., 2000).

There is also the possibility of a transitional effect (i.e., more than one intervention point due to early educational campaigns, process changeovers). To account for this possibility, separate parameter estimates were added in a sequential stepwise fashion to the most parsimonious models as was done in Masten and Hagge (2004). Specifically, the intervention point was moved 6 months after the actual implementation date and two additional parameters were included in a sequential stepwise fashion for 6 months before (i.e., the actual implementation) and 6 months after the intervention (12 months after actual implementation). The transitional effect was not significant.

There have been numerous proposed modifications to the structure of the GDL programs (Ferguson, 2003; Masten & Hagge, 2004) that may show lasting effects. As of 2006, 12 states restricted the use of cell phones for teenage drivers (Insurance Institute of Highway Safety, 2006). Limiting the potential for driver distraction is one factor that may further reduce the crash rates of teenage drivers (Ferguson, 2003; Hedlund et al., 2003). Although there may be additional modifications that can increase the effectiveness of the system, this study shows that GDL does appear to be successful. The insignificance of the intervention effect for the covariate series (i.e., drivers between 25 and 54) also provides support for this causal argument, providing evidence that GDL may be the only intervention factor creating a change in the crash rates of the overall driving population.

There were limitations associated with these analyses. The Iowa GDL program took effect in January 1999 but the 16-year-old drivers in that same year may have actually obtained their full license prior to January 1999. These drivers were not in the GDL program, but were included in the analysis because it was not possible to distinguish these different driver groups. All 16-year-olds are required to be in the Iowa GDL program for all subsequent years. It is recognized that these differences (in 1999) may bias the study results. However, if this period was not included, the time series models would not have been able to account for the variations that occur due to the onset of the program. The same assumption was made in regards to the analysis of the 17- and 18-year-old drivers. Moreover, the crash data used for this study include only police documented crashes, which is another potential bias due to under reporting of minor property damage only (PDO) crashes. Additionally, there may be limitations associated with the existence of the MSL in Iowa that may result in additional experience for the drivers who enrolled in this program. However, the enrollment in this program is relatively small when compared to the population of teenage drivers as discussed in the results section.

It is also important to note that the rate metric will influence the nature of the mechanisms underlying the effects, as noted by McKnight and Peck (2002). This study used a driver licensed-based population that included both teenage drivers with full licenses and also those with learner's permits. Using this subset provides a more direct evaluation of the target population that is specifically exposed to the intervention method. For example, 16-year-olds that do not drive or have a learner's permit are not exposed to the GDL intervention. This, however, is a limitation of the study because the inclusion of these drivers may impact the ability to evaluate the effectiveness of this program because the crash reduction may also be attributed to exposure rather than just the intervention. That notwithstanding, the results are still statistically significant for the 16- and 17-year-olds, thus the true effect may actually be stronger. This study does indicate that other research questions can be examined in order to improve the GDL programs and continue to make teenage drivers safer. For example, there was no evidence in Masten and Hagge (2004) that the California GDL program significantly reduced the number of fatalities and injuries caused by teenage drivers, but it did reduce the number of injuries and fatalities of teenage drivers at night, and those with passengers. Therefore, it would be interesting to examine whether injuries sustained would be similarly influenced by the Iowa GDL program. It would also be interesting to examine what components of the Iowa GDL are specifically causing the decrease in crash frequency among 16-year-old drivers. As noted earlier, another difference is the existence of the Minor School License in Iowa. Given the small percentage that obtains these licenses, they may not significantly impact the crash rates of 16-year-olds.

In summary, the Iowa GDL program appears to be effective for reducing crash likelihood in 16- and 17-year-old drivers, but not as effective in establishing lasting effects for 18-year-old drivers.

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