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Authors: Scott V. Masten and Robert A. Hagge
Research and Development Branch
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California's 1998 graduated driver licensing program was implemented to reduce the high crash risk of teenage drivers. Monthly per capita crash rates for 15-to-17-year-olds were analyzed using time series analysis. No overall reduction in total crashes or fatal/injury crashes was found immediately following program implementation or beginning 6 months later. The 12-month nighttime restriction was associated with significant sudden-permanent reductions of 0.44% in total crashes and marginally significant 0.45% in nighttime fatal/injury crashes. The 6-month passenger restriction was associated with reductions of 2.52% and 6.43% in total and fatal/injury teen passenger crashes, respectively. The fact that no overall reductions in crashes, and only small reductions in crashes associated with the restrictions, were found is not surprising given findings that teens and parents were either already practicing program requirements prior to implementation, or not fully complying with the program requirements afterwards. The findings provide support for passenger and nighttime restrictions.

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PREFACE

This report presents the results of an evaluation of the traffic safety impact of California's Graduated Driver Licensing Program for drivers younger than 18 years of age (CVC §12814.6). The purpose of the evaluation is to provide statistical information useful to traffic safety researchers and driver licensing program administrators in determining the effectiveness of the teen licensing program and its major components in reducing crashes involving young drivers. This project is part of the California Traffic Safety Program and was made possible through the support of the California Office of Traffic Safety, State of California, and the National Highway Traffic Safety Administration. The report was prepared by the Research and Development Branch of the California Department of Motor Vehicles under the administration of Cliff Helander, Chief. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of California or the National Highway Traffic Safety Administration.

ACKNOWLEDGMENTS

This study was conducted under the supervision of Robert Hagge, Research Manager II, who also contributed the design of the study, supervised all of the statistical analyses, and edited the final report. Emilie Mitchell, former Research Analyst II, wrote much of the computer code used to create the crash series, completed initial time series analyses, and wrote detailed instructions that eased the transition for the subsequent project leader. Eric Chapman, Research Analyst II, helped create the tables and helped in the analysis and interpretation of the time series results. Debbie McKenzie, Associate Governmental Program Analyst, helped create the figures and format the final report.

EXECUTIVE SUMMARY

Introduction

Teenage drivers have a much higher crash risk than do older drivers due to their fundamental lack of driving skill, inexperience at driving, tendency towards increased risk-taking, immaturity, inaccurate risk perception, and overestimation of driving skills (Janke, Masten, McKenzie, Gebers, & Kelsey, 2003). States have tried to mitigate the increased crash risk of teenagers by implementing modified driver licensing programs for teenagers that focus on improving their skills and reducing their exposure to those situations in which they are at the highest risk, such as driving at night or with young passengers. The modified licensing systems for teenagers usually include several stages leading to an unrestricted license. The licensing stages for teenagers typically include a supervised practice period, license restrictions, and accelerated post-licensing control actions that do not apply to adults. This report presents results of an evaluation of the safety impact of several enhancements made in July 1998 to improve the effectiveness of California's licensing program for drivers under age 18.

California's first teen licensing program (called the provisional licensing program), implemented in October 1983, included all of the following components for license applicants under age 18:

- A mandatory 1-month instruction permit period allowing driving only when supervised by a parent/guardian, spouse, or licensed adult 25 years of age or older.

- A parent/teen driver-practice guide that contains structured driving exercises that the teen must master before taking a drive test.

- A distinctive looking driver license, allowing easy identification of the driver as a provisional licensee.

- A 1-week wait after failing the written knowledge test and 2-week wait after failing the behind-the-wheel drive test before retesting.

- Parent certification that the teen successfully completed the exercises in the parent/teen guide and is skilled enough to pass the DMV drive test.

- An accelerated post-licensing control action program in which teens receive a warning letter after their first traffic violation or responsible crash, a 1-month restriction allowing only supervised driving after their second violation or at-fault crash in a 12-month period, a 6-month license suspension and 1-year probation after a third offense in 12 months, and extended license suspension or possible revocation after a fourth offense, violation of probation, failure to appear in court, or failure to pay a fine.

Hagge and Marsh (1988) evaluated the California provisional licensing program using time series analysis and also an assessment of individual driver records. They found that the program as a whole was associated with 5.3% lower per capita crash rates for 15- to-17-year-olds and 23% lower violation rates for 16-year-old licensed drivers.

California Vehicle Code Section 12814.6 added enhancements to the teen driver license program starting in July 1998. This program is called the graduated driver licensing (GDL) program. In addition to having to pass the vision, written, and drive tests, the California graduated licensing program evaluated in this report includes all of the components of the original provisional licensing program identified above plus:

- A minimum 6-month instruction permit period.

- Parent/guardian certification that the teen driver completed a minimum of 50 hours of behind-the-wheel practice (10 hours of which must be at night) supervised by a licensed parent/guardian, spouse, or adult 25 years of age or older, or a certified driving instructor.

- A 12-month restriction from driving between 12:00 a.m. and 5:00 a.m., unless supervised as defined above. Exceptions are granted for medical or family necessity, school activities, and employment needs, with a note signed by the proper authority such as a parent or principal and specifying the ending date for the exception.

- A 6-month restriction from driving with passengers under the age of 20, unless supervised as defined above. Exceptions are allowed under the same circumstances indicated above.

Method

Monthly statewide per capita crash rates for January 1994 to December 2001 were analyzed using Autoregressive Integrated Moving Average (ARIMA) intervention time series analysis to determine whether implementing the GDL enhancements in July 1998 changed the rate of crashes involving 15-to-17-year-old drivers, and in some cases the rates of crashes involving 16-year-old and 18-19-year-old drivers. The crash rates for adult drivers aged 24 to 55 were used as a control series in some of the analyses to account for history-related factors that would have affected crashes for both age groups. The following criterion crash series were created and analyzed in this evaluation:

1. Total crashes
2. Fatal/injury crashes
3. Proportion of total crashes occurring during 12:00-5:00 a.m.
4. Proportion of fatal/injury crashes occurring during 12:00-5:00 a.m.
5. Proportion of total crashes involving passengers under age 20
6. Proportion of fatal/injury crashes involving passengers under age 20
7. Total crashes involving 16-year-olds
8. Fatal/injury crashes involving 16-year-olds
9. Total crashes involving 18-19-year-olds
10. Fatal/injury crashes involving 18-19-year-olds

The first two series were analyzed to evaluate the impact of GDL as a whole. The analyses of crashes in which a 16-year-old was the youngest involved driver are conceptually less biased for purposes of evaluating the impact of the GDL enhancements, because of a shorter transition time period for all drivers in this age group to be completely under the new GDL program requirements. The four series involving proportions of crashes during the restricted time period and involving passengers less than 20 years of age were used to evaluate the impact of the nighttime restriction and passenger restriction components of GDL, respectively. The analyses of 18-19-year-old drivers in crashes were conducted to determine if the program had any positive or negative effects on this age group. Two additional crash series not listed above were also analyzed. These consisted of crash involvements for which a single crash incident was typically assigned multiple times (one "crash" count assigned to each driver involved).

Results

This study analyzed several different crash types and age-groups, various intervention models, and flexible intervention start points to determine whether the enhancements made to the California teen licensing program in July 1998 resulted in crash reductions for teen drivers. The results are summarized below:

- No overall reduction in total crashes or fatal/injury crashes was found immediately following program implementation or beginning 6 months later. This outcome was the same even when transition components were added to the models to adjust for the influence of the influx of teen licensees before the implementation date, when the adult series was included as a control variable, when only 16-year-old driver crashes were analyzed, and when the rates were calculated as crash involvements rather than being based on the youngest involved driver. However the program was found to be associated with a 19.45% gradual-permanent increase in total crashes for 18-19-year-olds 6 months after the program was implemented (about 9,464 additional crashes per year). No significant effect was found in the 18-19-year-olds fatal/injury crashes.

- The 12-month nighttime restriction was associated with a sudden-permanent 0.44% reduction in total crashes occurring during the hours of midnight to 5:00 a.m. for 15-17-year-olds starting 1-year subsequent to the implementation of the nighttime restriction. The results also suggested a marginally significant sudden-permanent 0.45% reduction in their nighttime fatal/injury crashes starting 1-year subsequent to the program implementation. These effects translate into savings of 153 total crashes and 68 fatal/injury crashes annually for 15-17-year-olds. These crash savings estimates are based on an assumption that the GDL night driving restriction did not increase daytime crashes.

- The 6-month passenger restriction was associated with a marginally significant sudden-permanent 2.52% reduction in 15-17-year-old total teen passenger crashes, and a significant gradual-permanent reduction stabilizing at -6.43% in fatal/injury passenger crashes when using an intervention date 1-year subsequent to the program start date. These effects equate to savings of 878 total crashes and 975 fatal/injury crashes annually for 15-17-year-olds. These crash savings estimates are based on an assumption that the GDL passenger restriction did not cause an increase in non-passenger crashes for the 15-17-year-old age group.

Discussion
The fact that no overall reductions were found in teen total or fatal/injury crash rates from the program start date or from a 6-months subsequent date is not surprising given the Williams, Nelson, and Leaf (2002) findings indicating that many teens were simply applying for their instruction permit earlier to avoid delaying licensure, and that only small increases were found in the percentages of teens receiving additional hours and miles of supervised on-the-road practice during this longer instruction permit period. In addition, the reductions associated with the nighttime and passenger restrictions were

small and occurred some months later in time and therefore would not have helped detect an effect using the time periods analyzed for the overall analyses.

The fact that an increase was found in total crashes for 18-19-year-olds suggests that GDL programs may have unintended negative consequences for this and possibly other age groups. One possibility for this finding is that any positive effects of the program may not continue into later years and that 16-17-year-olds under the program might not be as safe and skilled at age 18 as they would have been without the GDL restrictions. The increase in 18-19-year-old crash rates could also be due to a higher percentage of that age group being licensed due to younger teens waiting to license until age 18 to avoid the program. In any case, it is recommended that 18-19-year-olds not be used as a comparison group for evaluations of GDL programs because it appears that drivers in this age group are impacted by such programs.

Because the post-program crash rates for teens were compared to their pre-program rates, and these pre-program rates already reflected the influence of crash reductions associated with the original teen licensing program evaluated by Hagge and Marsh (1988), any benefit of the program enhancements made in 1998 was expected to be only marginal incremental reductions in crash rates. Indeed, the observed effects for the nighttime and passenger restrictions were modest in size. If this evaluation had compared the crash rates under this enhanced program with all of its components to some theoretical set of teen crash rates for drivers under no program, it is much more likely that significant and larger decreases in overall total and fatal/injury crash rates associated with the program would have been found.

Finding reductions in total and fatal/injury nighttime crashes is consistent with results from other states that have adopted nighttime restrictions (Ferguson, Leaf, Williams, & Preusser, 1996; McKnight, Hyle, & Albrecht, 1983). The use of a 1-year delayed intervention date for analyzing the effects of the nighttime and passenger restrictions seems justified because it both reduced transition bias associated with the increase in teen licensure around the time the enhancements were implemented and allowed time for more teens to be fully under the program requirements. This latter issue is especially relevant for evaluating the restrictions because they do not take effect until the teens complete the 6-month instruction permit period. The percentage reductions associated with the nighttime restriction were, however, quite small. Larger nighttime crash reductions may have been realized if the nighttime restriction began at an earlier time (e.g., 11:00 p.m. or earlier), as has been suggested by traffic safety experts (McKnight, 1986; Williams & Mayhew, 2003). In addition, although around 90% of teens complied for at least the first 6 months of the restriction, only 60% of teens were found to have not driven after midnight for their first full year after licensure (Williams et al., 2002). Clearly if parents could be motivated to not permit driving for the full term of the restriction, even larger reductions in nighttime teen crashes might be realized.

California was the first state to implement a meaningful teen passenger restriction (Williams et al., 2002). Finding that the passenger restriction was associated with modest, but significant reductions in both total and fatal/injury crashes is noteworthy because it indicates that passenger restrictions are effective components of GDL programs. Although compliance with the 6-month passenger restriction was not found to be very high (around 50%), not transporting other teenagers during the first 6-months of driving represented the largest actual change in behavior before and after the GDL enhancements were implemented (Williams et al., 2002). Therefore it is not surprising that the effects of the passenger restriction were larger than those for the nighttime restriction. Given the high crash risk of teen drivers when they transport other teenagers, finding ways to increase the willingness and ability of parents to enforce the passenger restriction would likely result in additional crash savings.

Although the California GDL program evaluated in this report is considered to be one of the strongest in the United States, there are additional features that could be added or changed that may serve to strengthen the program even further. In addition to starting the nighttime restriction at an earlier time and finding ways to increase compliance with the nighttime and passenger restrictions, the program could be improved by making a teen's advancement from one stage of licensure to another contingent upon maintaining a crash- and violation-free driving record, and by tying the passenger and nighttime restrictions to the intermediate licensing stage rather than to a set period of time (McKnight, 1986). Furthermore, compliance with the nighttime and passenger restrictions could be increased by allowing law enforcement officers to stop teens simply because they believe they are violating these restrictions (i.e., primary enforcement).

Other authors (e.g., Mayhew & Simpson, 2002) have recommended that driver education and training be integrated into GDL programs so that they are multi-staged, with a basic driver education course before teens learn how to drive and an advanced course after they have gained some experience driving on the road. More complex topics, such as hazard perception, might be better taught in the advanced course where experience on the road might make these topics more understandable. Results of a recent evaluation (Masten & Chapman, 2003) showing that home-study driver education courses were just as effective as classroom-based courses for teaching basic driver education content may provide a means for removing some of the potential roadblocks for integrating such a two-staged driver education and training system with California's GDL program. The use of home-study driver education for the first stage of a tiered driver education and training program may also increase parental involvement in their teen's early driving experience, and motivate them to more fully enforce the GDL restrictions.

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INTRODUCTION

Teenage drivers have a much higher crash risk than do older drivers due to their fundamental lack of driving skill, inexperience at driving, tendency towards increased risk-taking, immaturity, inaccurate risk perception, and overestimation of driving skills (Janke, Masten, McKenzie, Gebers, & Kelsey, 2003). States have tried to mitigate the increased crash risk of teenagers by implementing modified driver licensing programs for teenagers that focus on improving their skills and reducing their exposure to those situations in which they are at the highest risk, such as driving at night or with young passengers. The modified licensing systems for teenagers usually include several stages leading to an unrestricted license. The licensing stages for teenagers typically include a supervised practice period, license restrictions, and accelerated post-licensing control actions that do not apply to adults. This report presents results of an evaluation of the safety impact of several enhancements made in July 1998 to improve the effectiveness of California's licensing program for drivers under age 18.

Licensing Programs for Teenagers

'Provisional Driver Licensing' (PDL) and 'Graduated Driver Licensing' (GDL) are common names for licensing programs designed for teenage drivers. Which term is used typically depends on when the program was implemented (earlier programs usually called PDL) or whether the program includes an intermediate licensing stage in which teens are gradually exposed to riskier driving situations by sequentially removing licensing restrictions (typically referred to as GDL). Because these two names are often used interchangeably and all such programs are designed for teenage drivers, the remainder of this report will usually not differentiate between the two.

Given that research on teen drivers has shown that increased driving experience is associated with reduced crash risk (Ferguson, 1996; Mayhew & Simpson, 1990; Simpson & Mayhew, 1992), many states, provinces, and countries have introduced licensing programs for teenage drivers that gradually lift initial licensing restrictions to ease them into higher risk driving situations (Foss & Goodwin, 2003; Mayhew & Simpson, 1984, 1996; McKnight, 1996; Shope & Molnar, 2003; Simpson, 2003). These programs may include: (a) mandatory periods of supervised driving instruction on an instruction permit, (b) restrictions from driving during certain hours at night, (c) restrictions from carrying passengers under a certain age (usually age 20), (d) accelerated and more severe penalties for drivers who violate traffic laws or cause crashes, and (e) zero-tolerance or lower blood alcohol concentration (BAC) restrictions (Mayhew & Simpson, 1996; McKnight, 1996; Williams & Mayhew, 2003). The license restrictions and accelerated post-licensing control actions are normally in effect during all or part of the 'learner' (instruction permit) and 'intermediate' (restricted) licensing stages. Some teen licensing programs include minimum required hours of supervised driving practice, or may lower the age or time requirements for obtaining an instruction permit or intermediate license if the person has completed driver education and driver training instruction.

The more stringent programs typically make advancement from one stage of licensing to another contingent upon maintaining a crash- and violation-free driving record, while other programs make advancement to the next stage based solely on time (e.g., a

12-month night driving restriction). Other authors have suggested additional restrictions such as restricting novice teens from driving on freeways and during weekends (McKnight, 1996; Mayhew & Simpson, 1984, 1996). These types of restrictions are not as common, although they are supported by research findings (e.g., Cooper, Pinili, & Chen, 1995). Restrictions on driving at night and transporting young passengers are considered to be very important features of any teenage licensing program, given the high crash risk for teenagers under these situations (Lin & Fearn, 2003; Williams & Mayhew, 2003). Night driving curfews have been shown to reduce driving during the restricted hours and discourage early licensure (Williams, Lund, & Preusser, 1985). Driving restrictions and curfews have been found to result in less risky driving especially when licensure is contingent upon not receiving traffic violations during the restricted stage (McKnight, 1986).

To date, 37 states have adopted comprehensive modified licensing programs for teens, and 47 states and the District of Columbia have implemented one or more of the major components mentioned above (Shope & Molnar, 2003). Programs in some jurisdictions apply to new drivers of any age (e.g., Nova Scotia and Ontario), while others apply only to novice drivers under certain ages (e.g., under age 25 in New Zealand and under age 18 in most U.S. states, including California). States that have adopted even some of the key components, such as a nighttime restriction, have realized lower teenage crash rates (Ferguson, Leaf, Williams, & Preusser, 1996; McKnight, Hyle, & Albrecht, 1983; Preusser, Ferguson, & Williams, 1999). In fact, evaluations of these programs or their components have generally found that they are associated with reductions in crashes, although there is a lot of variation in the observed effect sizes (ranging from 4% to 60%). The high variability is probably due to the fact that the programs differ in their components, some being more comprehensive and strict than others, and to differences in methodology used in the evaluations (e.g., different crash metrics and statistical analyses). A fairly thorough summary of the results of a number of evaluations of licensing programs for teenagers in various jurisdictions can be found in McKnight and Peck (2002) and Masten (in press).

California's Licensing Program for Teenagers

To obtain a learner's permit in California, teens younger than age 18 must have completed or be simultaneously enrolled in both driver education and driver training courses or have completed driver education and be enrolled in a driver training course. They also must pass vision and written knowledge tests. The minimum age to apply for an instruction permit is 15 years. To obtain their driver license they must be at least 16 years of age and pass a drive test.

California's first teen licensing program, implemented in October 1983, included the following components for license applicants under age 18:

- A mandatory 1-month instruction permit period allowing driving only when supervised by a licensed parent/guardian, spouse, or adult 25 years of age or older, or a certified driving instructor.

- A parent/teen driver-practice guide that contains structured driving exercises that the teen must master before taking a drive test.

- A distinctive looking driver license, allowing easy identification of the driver as a provisional licensee.

- A 1-week wait after failing the written knowledge test and 2-week wait after failing the behind-the-wheel drive test before retesting.

- Parent certification that the teen successfully completed the exercises in the parent/teen guide and is skilled enough to pass the DMV drive test.

- An accelerated post-licensing control action program in which teens receive a warning letter after their first traffic violation or responsible crash, a 1-month restriction allowing only supervised driving after their second violation or at-fault crash in a 12-month period, a 6-month license suspension and 1-year probation after a third offense in 12 months, and extended license suspension or possible revocation after a fourth offense, violation of probation, failure to appear in court, or failure to pay a fine.

Hagge and Marsh (1988) evaluated the California provisional licensing program using time series analysis of statewide crash rates and also an assessment of individual driver records. They found that the program as a whole was associated with 5.3% lower per capita crash rates for 15-to-17-year-olds and 23% lower violation rates for 16-year-old licensed drivers. Compared to the adult program, the accelerated post-licensing control action program for teenagers was found to be superior for reducing subsequent 2-year total crash and violation rates for teens, and increasingly more effective at higher point counts. The findings also suggested that the accelerated program was more effective than the adult program at reducing teen fatal/injury crash rates. Hagge and Marsh judged that a reduction in driving exposure related to delaying licensure and the 1 month instruction permit requirement, and the earlier sanctioning of drivers violating traffic laws and causing crashes, largely contributed to the safety benefits of California's provisional licensing program found in the study.

Even though the California program was found to reduce teen crash rates, teenage drivers remained the single highest risk age group of California drivers after the program was implemented (Aizenberg & McKenzie, 1997; Romanowicz & Gebers, 1990). In July 1998 the California Legislature enhanced the licensing program for teenagers in response to the recalcitrant high crash risk of teenage drivers in California and the fact that California's licensing program for teenagers did not include some of the components more recently considered by experts to be essential for an optimal program, such as nighttime and passenger restrictions. In addition, the California Legislature implemented a zero-tolerance alcohol law in 1994, which results in a 1-year license suspension for anyone under the age of 21 apprehended while driving with a BAC of 0.01% or higher, and has had primary enforcement of its mandatory seatbelt law since 1993. The enhanced California teen licensing program (now called GDL) is considered to be quite comprehensive and contains all of the components of an optimal system, with the exception of making advancement from one stage of licensing to another contingent upon maintaining a crash- and violation-free driving record (Williams & Mayhew, 2003).

In addition to having to pass the vision, written, and drive tests, the California graduated licensing program evaluated in this report (California Vehicle Code Section 12814.6; see the Appendix) includes all of the components of the original provisional licensing program identified above plus:

- A minimum 6-month instruction permit period.

- Parent/guardian certification that the teen driver completed a minimum of 50 hours of behind-the-wheel practice (10 hours of which must be at night) supervised by a licensed parent/guardian, spouse, adult 25 years of age or older, or certified driving instructor.

- A 12-month restriction from driving between 12:00 a.m. and 5:00 a.m., unless supervised as defined above. Exceptions are granted for medical or family necessity, school activities, and employment needs, with a note signed by the proper authority such as a parent or principal and specifying the ending date for the exception.

- A 6-month restriction from driving with passengers under the age of 20, unless supervised as defined above. Exceptions are allowed under the same circumstances indicated above.

A survey of California teens and their parents regarding the new teen licensing system suggested widespread support for the program enhancements by parents whose teens were subject to the new requirements and restrictions (Williams, Nelson, & Leaf, 2002). These authors surveyed two groups of teenagers who were applying for a driver license in California, as well as their parents. One group was sampled from April through June 1998, right before the July 1998 program implementation date, and the other was sampled from May through July 1999. The first group was not subject to the new program requirements because only persons who applied for an instruction permit on or after July 1, 1998 were subject to the law changes. The second group of teenagers was subject to the new program requirements. Compliance with the enhanced program provisions is essential for them to be effective. The results of their survey indicated widespread, although not universal, compliance with holding the instruction permit for 6 months (97%), and the 50 hours of supervised instruction requirement (81%—10 hours at night 79%). However, much lower compliance was reported by the parents regarding the 1-year nighttime driving restriction (59%), and the 6-month passenger restriction (52%). Not surprisingly, the parents tended to report more compliance with the requirements and restrictions than did their teenagers.

As stated above, compliance with the new requirements is important for the enhanced program to reduce crash rates. However, the findings in the Williams et al. (2002) survey indicate that a significant percentage of parents were already imposing similar requirements and restrictions on their teenagers before July 1998, which has major implications for the results of this evaluation. In terms of percentage-point increase, their findings show that only 20% more teens held their instruction permit for 6 months or longer after the enhancements (97%) compared to those who applied before the program (77%). In addition, only 14% more drove the 50-hours of required supervised practice (67% before vs. 81% after), and only 10% more at night (69% before vs. 79% after). These increases, although statistically significant, indicate that a high percentage of parents were already requiring these things of their teenagers before the enhancements were implemented. Similarly, the percentage of parents indicating that they did not allow their teens to drive after midnight for the full 1 year (54%) was only 5 percentage points higher after July 1998 (59%). Only for the passenger restriction was the percentage-point gain (38%) much higher after the law change (14% before vs. 52% after), but overall compliance was not very high for either of the new restrictions.

It should be noted that enforcement of the nighttime and passenger restrictions is not likely to be high because law enforcement officers are not permitted to stop teens solely for violating these restrictions (secondary enforcement), and because the penalties for violations are not very severe. In fact, such violations do not count as negligent operator points on the driver record and do not result in post-licensing control actions. Instead, violations of the restrictions are handled administratively by judges, who may impose 8 to 16 hours of community service or a $35 fine for a first offense and 16 to 24 hours of community service or a $50 fine for subsequent offenses. These factors conceivably could tend to decrease the commitment of teenagers to obey, and parents to enforce, the restrictions.

One additional finding from their survey with implications for the current evaluation is that the program does not appear to have resulted in a delay of licensure. Specifically, teenage drivers applying for a license before and after the program enhancements did not differ in the average age at licensure (the average age being 16 years and 6 months for both groups). This may seem surprising given that the instruction permit period was extended from 1 to 6 months, but it can probably be largely explained by the fact that teens applied for their instruction permits 3 months earlier on average after the program than before. This allowed them to obtain their provisional license at the same age on average as those who applied before the instruction permit period was extended. Together, these findings suggest that teens drove earlier and had a higher risk exposure level after the program started. Recall that the reduction in driving exposure due to delayed licensure was judged to be one of the most important factors for the effectiveness of California's initial teen licensing program evaluated by Hagge and Marsh (1988); this factor does not appear to be in play in the current evaluation.

The longer period of driving on an instruction permit would not be expected to result in significantly higher crash rates because supervised driving is generally considered to be of low risk (Williams, 2003; Williams, Preusser, Ferguson, & Ulmer, 1997). In fact, the longer instruction permit period could arguably decrease crash risk because it would have allowed teens to gain more supervised driving practice and become more skillful before they obtained their license. Regarding gaining more supervised driving experience, as mentioned above the Williams et al. (2002) survey results showed that only a slightly higher percentage of parents (14 percentage points higher) reported that their children practiced for at least 50 hours after the program enhancements were implemented (81%) compared to beforehand (67%). In addition, there was only a 22 percentage-point increase in the number of teens reporting that they practiced driving for 500 miles or more after the program enhancements were implemented (52%) compared to beforehand (30%). These results do not suggest that the longer instruction permit period resulted in widespread increased supervised driving practice as might have been hoped. Given the likely nominal positive effect this minimal increased practice would be expected to have, the fact that teens were driving (albeit supervised) at an earlier age on average, and the finding that the program did not result in a delay of licensure (i.e., an older average licensing age), it is unlikely that the longer instruction permit period had much of a positive safety benefit.

The low overall levels of compliance with the passenger and nighttime driving restrictions and the modest increases in the percentages of parents restricting their teen drivers after the enhancements, along with a similarly modest increase in the percentage of parents requiring additional supervised practice, would not lead one to believe that the program enhancements would have had a substantial impact on the crash rates of teen drivers. In addition, because the crash rates of teens analyzed in this evaluation already reflect the influence of reductions associated with the original teen licensing program evaluated by Hagge and Marsh, any benefit of the program enhancements made in 1998 would be expected to be marginal.

Although this report presents the official California Department of Motor Vehicles' evaluation of the enhanced California GDL program, other evaluations of the program have been completed. Results of two evaluations of California's program by the Automobile Club of Southern California suggested positive results of the program (Bloch, 2000; Bloch, Shin, & Labin, 2002). However, the analysis methods used in these evaluations did not adequately adjust for preexisting trend in the crash data and used questionable methodology. Results of another evaluation of the California program sponsored by the California State Automobile Association (Atkins, Cooper, & Gillen, 2002) also suggested reductions in crashes caused by 16-year old drivers associated with the program, but the methods used in that study were of questionable validity and must therefore also be considered equivocal. Finally, a quasi-experimental pre-post comparison of 16-year-old drivers in San Diego County, California by Smith, Pierce, Ray, and Murrin (2001) did not find changes in the per-driver crash rates for 16-year-olds following the implementation of the GDL law, although their results did suggest a 20% decrease in per-capita crash and injury rates. However, the authors did not account for preexisting trend in the data that might explain the observed per-capita reduction.

The current evaluation is considered superior to the four just mentioned primarily because it uses an analytical approach that accounts for trend and seasonality in the data before any potential effect of the program enhancements is evaluated.

METHODS

Overview

Monthly statewide per capita crash rates for January 1994 to December 2001 were analyzed using Autoregressive Integrated Moving Average (ARIMA) intervention time series analysis to determine whether implementing the GDL enhancements in July 1998 changed the rate of crashes involving 15-to-17-year-old drivers in California. The crash rates for adult drivers aged 24 to 55 were used as a control series in some of the analyses to account for history-related factors that would have affected crashes for both age groups. The collection of time series data and analysis procedures are described below.

Data

Teenage drivers aged 15 to 17 years comprised the treatment group for purposes of the evaluation, and adult drivers aged 24 to 55 years were used as a control group. All drivers aged 15 to 17 who applied after the program start date were subject to the GDL program requirements during the period in which they hold an instruction permit or provisional driver license. Age 24 was chosen as the lower bound for the control group because 24-year-olds were the youngest drivers who would not have been subject to the new GDL program during the time period analyzed in the evaluation. The criterion measures used to evaluate the overall impact of the GDL program are different types of crashes per population unit for 15-to-17-year-old drivers, and in some cases separately for 16-year-old and 18-19-year-old drivers. To evaluate the effect of the restrictions, additional analyses were conducted to determine whether the percentage representation of crashes occurring during 12:00-5:00 a.m., or involving passengers under age 20, changed after the GDL enhancements.

The traffic crash data used in this evaluation were obtained from the California Highway Patrol's (CHP's) Statewide Integrated Traffic Records System (SWITRS). Given that the GDL program was implemented the first day of July 1998, the first 54 months (January 1994 to June 1998) represented the pre-implementation time period for the analyses, while the last 42 months (July 1998 to December 2001) comprised the post-implementation time period. To create the per capita crash rates, counts of crashes involving at least one driver of a passenger vehicle, pickup, or motorcycle were assigned to an age group based on the age of the youngest driver involved in the crash. If multiple driver age groups were involved, the crash was attributed to the youngest driver.

Annual population data by age were obtained from the California Department of Finance for the years 1993 to 2002. Monthly population counts were interpolated from the annual counts by assuming linear increases and decreases in the population across all 12 months of a given year. Per capita crash rates were computed by dividing the monthly number of crashes for each age group by the monthly estimated population in the age group.

The following criterion crash series were created and analyzed in this evaluation:

1. Total crashes
2. Fatal/injury crashes
3. Proportion of total crashes occurring during 12:00-5:00 a.m.
4. Proportion of fatal/injury crashes occurring during 12:00-5:00 a.m.
5. Proportion of total crashes involving passengers under age 20
6. Proportion of fatal/injury crashes involving passengers under age 20
7. Total crashes involving 16-year-olds
8. Fatal/injury crashes involving 16-year-olds
9. Total crashes involving 18-19-year-olds
10. Fatal/injury crashes involving 18-19-year-olds

The first two series were analyzed to evaluate the impact of GDL as a whole. The analyses of crashes in which a 16-year-old was the youngest involved driver are conceptually less biased for purposes of evaluating the impact of the GDL enhancements, because of the shorter transition time period for all drivers in this age group to be completely under the new GDL program requirements. The four series involving proportions of crashes during the restricted time period and involving passengers less than 20 years of age were used to evaluate the impact of the nighttime restriction and passenger restriction components of GDL, respectively. The analyses of 18-19-year-old drivers in crashes were conducted to determine if the program had any positive or negative effects on this age group.

Two additional crash series not listed above were analyzed. These consisted of crash involvements for which a single crash incident was typically assigned multiple times (one "crash" count assigned to each driver involved). These series were analyzed to determine if using crash involvement rates would yield results consistent with those from the analysis of total crash rates based on the age of the youngest involved driver. One analysis was conducted for total crash involvements and another was conducted for fatal/injury crash involvements.

Although it would have been desirable to also analyze crash rates per driver (including those who were not fully licensed) and rates per licensed driver, it was not possible to calculate these rates because the crash volumes from SWITRS include crashes for permit-holding, licensed, and unlicensed drivers while DMV has counts of licensed drivers only.

Analyses

ARIMA intervention time series analysis (McCleary & Hay, 1982) was used to create mathematical models that best described the crash rates of the 15-to-17-year-old drivers using auto-regressive (AR), integrated (I), and moving average (MA) components. The full multivariate model developed for some of the criterion-measure series included the corresponding crash rate series of 24-to-55 year olds as a covariate to reduce bias in the teen series caused by temporary or long-term effects of historical events other than the GDL program. It was assumed for purposes of the analysis that such extraneous factors (e.g., changes in general traffic safety laws, traffic and weather conditions, etc.) would influence both age groups equally. A good ARIMA model would account for any seasonal fluctuations and upward or downward trend that might otherwise obscure, or be mistaken for, a program effect. After the appropriate ARIMA model parameters were identified and estimated and parameters representing any other explanatory (or control) variables were added to the model, the intervention effect was evaluated by adding additional model parameters representing the intervention. Because ARIMA intervention analysis accounts for trend and seasonality in the data, it provides more statistical power and a less biased assessment of the intervention effect than do other techniques based on linear regression models.

The multivariate time series models included the following four additive components after any necessary differencing of the time series data was performed:

1. the covariate (adult) series multiplied by a coefficient designated β;

2. a multiplicative combination of autoregressive (AR) and/or moving average (MA) factors that best described the seasonal and nonseasonal variation—trends, cycles, autocorrelations, and so forth—in the treatment (15-17-year-old) series that was not accounted for by the covariate (this variance being commonly referred to as 'noise');

3. an intervention component that characterized the hypothetical effect of the program on the treatment series; and

4. error, that portion of variance in the dependent variable that remained unexplained (which would be minimized by a best-fitting model).

The final ARIMA models created in this study included (with the exception of the transition elements discussed later in this section) only parameters that were statistically significant at an alpha level of .05 (i.e., those that had less than a 5% likelihood of being found to be significant due to chance alone). Meta-diagnosis of competing alternative ARIMA models was completed to ensure that the most parsimonious models were chosen.

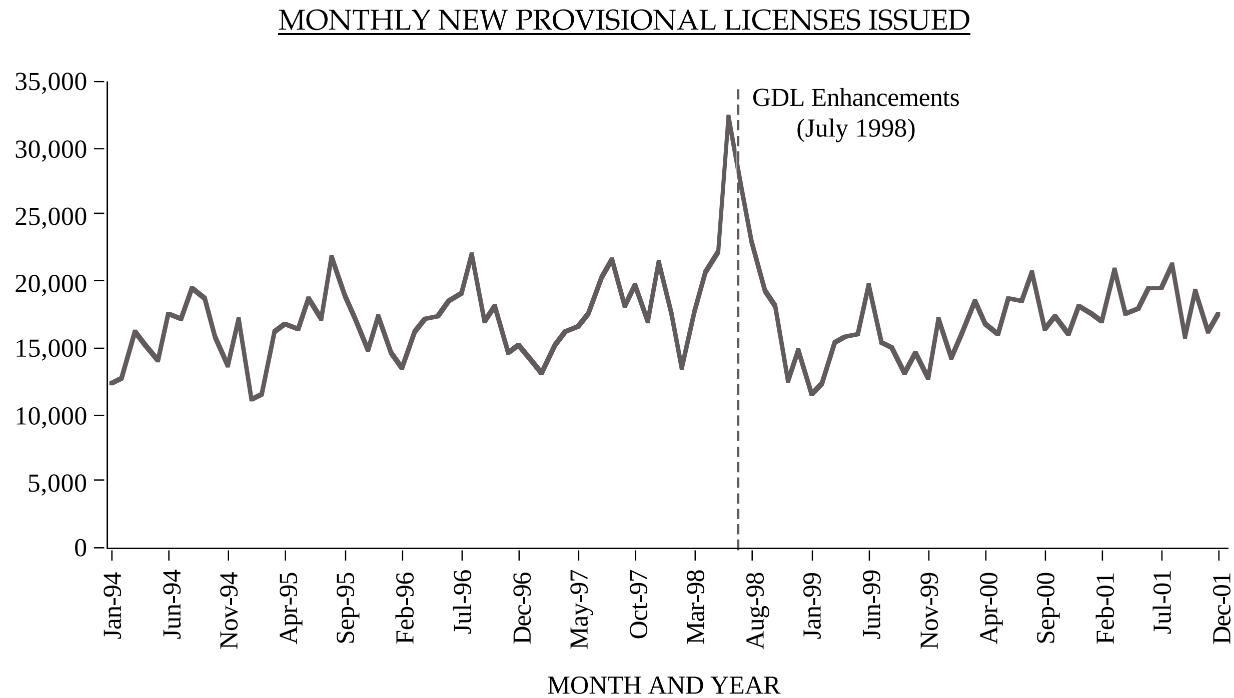
The teen and adult total and fatal/injury crash series were first modeled as separate univariate series to determine whether there were any changes in the series' levels coinciding with the start of GDL. Then, to evaluate the overall impact of GDL, the teen total and fatal/injury crash series were modeled using the adult series as a covariate (or explanatory variable) to account for common variance in the two series (such as might be due to reduced driving in both age groups resulting from increases in gasoline prices for example). Underlying the use of the adult series as a control for the teen series is the assumption that changes in the behavior of the adult series represents a baseline level of what would have been expected in the teen series in the absence of the GDL program. Because the adult series would be expected to model additional variability in the teen series beyond the univariate ARIMA structure, together with its functioning as a control series, the multivariate models represent a more powerful and valid assessment of GDL program impact than do the univariate models.

After the ARIMA models for either the univariate or multivariate series were completed, three different sets of parameters were added to each model one at a time to test three different hypotheses of the intervention's impact on teen crash rates: (a) gradual-permanent, (b) sudden-temporary, and (c) sudden-permanent. All three types of interventions were evaluated for goodness-of-fit to see which, if any, best modeled the impact of GDL. The direction, size, and statistical significance of the intervention parameter estimates defined the nature of the shift, if any, in the level of the treatment series caused by the GDL program.

The impact of the GDL program was expected to occur gradually and be permanent to reflect the gradual increase in the proportion of individuals who fell under the requirements of the GDL program over time. This gradual infusion of GDL drivers would result from the exclusion from the GDL program requirements (including the nighttime and passenger restrictions) of applicants who applied for a license before July 1998, even though they received their license after that date. By July 2001, all licensed 16-to-17-year-old drivers were subject to the requirements of GDL. Although a gradual-permanent change in the teen series was the most logical expected GDL effect, sudden-temporary and sudden-permanent impact models were also assessed.

In addition to the gradual increase in the proportion of teen drivers under the program over time, implementing GDL resulted in two other factors that likely affected the teen crash rates: (a) some teens may have applied earlier than they normally would have to avoid being in the program, and (b) some teens may have delayed licensure until age 18 to avoid being in the program. Figure 1 shows counts of monthly new provisional licenses issued and counts of outstanding provisional licenses from January 1994 to December 2001. Monthly counts of provisional licenses outstanding were interpolated from biannual counts by assuming linear increases in licenses issued and decreases in drivers turning age 18 across each 6-month period.

As can be seen in the figure, much higher volumes of provisional licenses were issued immediately before GDL was implemented, at which time the total number of outstanding provisional licenses also increased dramatically, remained higher than usual, and then dropped lower than was the case before the program was implemented. Simply put, the transition resulted in having more teen drivers on the road for some time immediately before and after the date that the GDL law was implemented. This sudden increase in licensed driver volumes likely affected teen crash rates and may have caused confounding transition effects in the analyses. Therefore, it would be expected that teen crash rates would temporarily increase for the periods immediately before and after GDL was implemented, all else being equal. In an attempt to account for this transition effect, separate parameter estimates were added to the time series models to account for possible changes in the series' levels during the 6 months before, 6 months after, and in some cases the second 6-month period after July 1998. The effective intervention points evaluated in these transition models were therefore January 1, 1999 (6 months after the actual implementation date) and in some cases July 1, 1999 (12 months after the intervention date). Incidentally, the survey findings of Williams et al. (2002) showing no change in the average age at licensure would likely not have been affected by this temporary increase in license volumes because their survey time frame occurred well after the rush of new licensees.



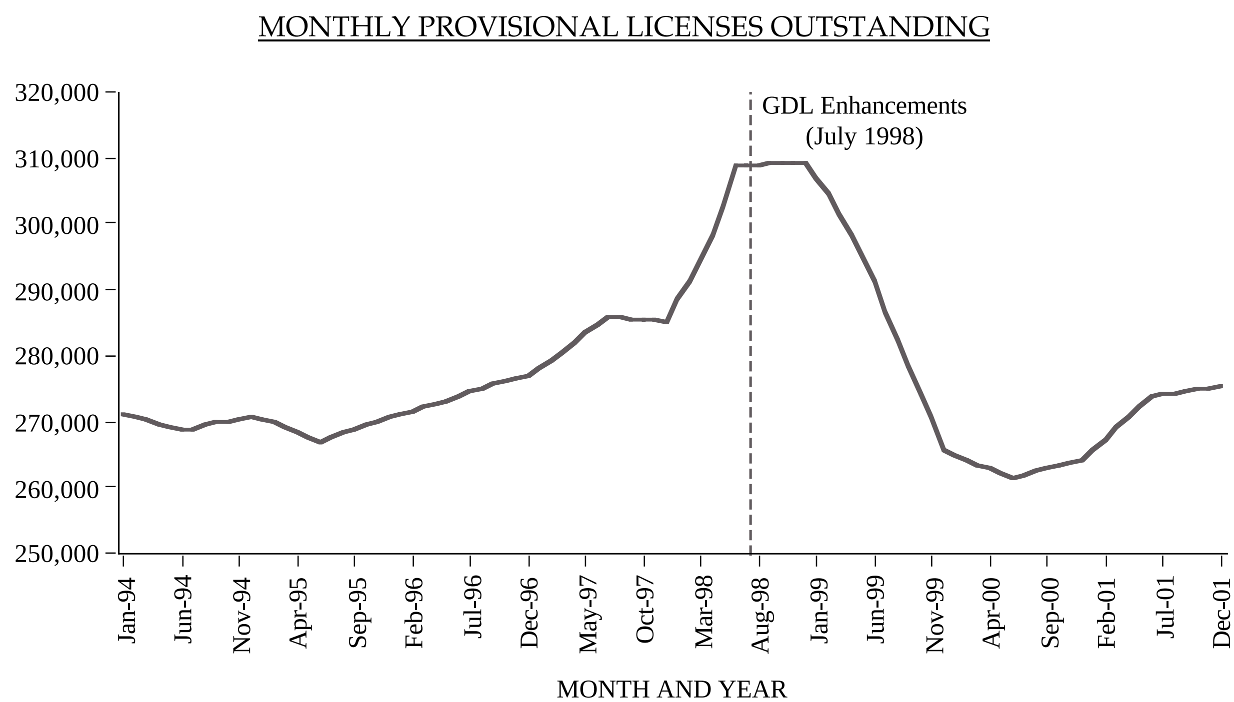


Figure 1. Monthly counts of new provisional licenses issued and total provisional licenses outstanding from January 1994 through December 2001.

The parameter structure representing the gradual-permanent intervention effect was $\frac{\omega}{1-\delta}$, where ω represents the treatment effect in units of crash rate the first month following intervention, and δ quantifies how quickly a stable impact was realized during subsequent months (the larger the value, the longer it took to reach an asymptote). The total change in the series level due to intervention for this effect was estimated as $\frac{\omega}{1-\delta}$. The parameter structure representing the sudden-temporary effect was the same, except that $\frac{\omega}{1-\delta}$ represented the total displacement of the series level (e.g., the total volume of crashes saved during the period before the crash rate series returned to its preexisting level). The transfer function for the sudden-permanent intervention component was indicated by ω, which reflected the average change in series level after intervention. The existence of a change in the level of the series subsequent to intervention (i.e., a program impact) is indicated by the presence of a statistically significant ω parameter in the intervention component. Negative ω parameters indicate a decrease in crashes subsequent to GDL, whereas positive values indicate that the crash rates increased. When there is statistically significant evidence of program impact, the statistical significance of δ is assessed to determine how well the theoretical change model (sudden or gradual) fits the data. If ω is not significant, the effect is considered to be nonsignificant. In addition, if δ is negative it indicates an unstable oscillating effect that could not be reasonably argued to have been caused by the program, and in this event the intervention effect modeled would be rejected. (According to McDowall, McCleary, Meidinger, and Hay [1980], a value of δ that is negative indicates that the time series system is unstable.)

RESULTS

Overall Total Crash Analyses

Plots of monthly total crashes per 1,000 population for 15-17-year-olds and 24-55-year olds are shown in Figure 2. The implementation of the GDL enhancements on July 1, 1998 is represented by the vertical dashed line shown in the figure.

Visual inspection of the data suggests that the total crash rates for 15-17-year-olds steadily declined throughout the time series period, with the exception of a temporary increase immediately before and after the program was implemented. The adult series appears to have remained flat throughout the same time period. There does not appear to be a significant change in either series coinciding with July 1, 1998, although the teen rates appear higher for the periods 6-months before and after the program. It should be emphasized that it can be very difficult to judge whether or not there was a change in the series based solely on a visual inspection of the data. What may appear to the naked eye as an intervention effect may prove to be nonsignificant when analyzed by the appropriate statistical test. On the other hand, where there does not appear to be an intervention effect, a statistically significant change may have indeed occurred. It is even more difficult to visually detect differences between two or more time series.

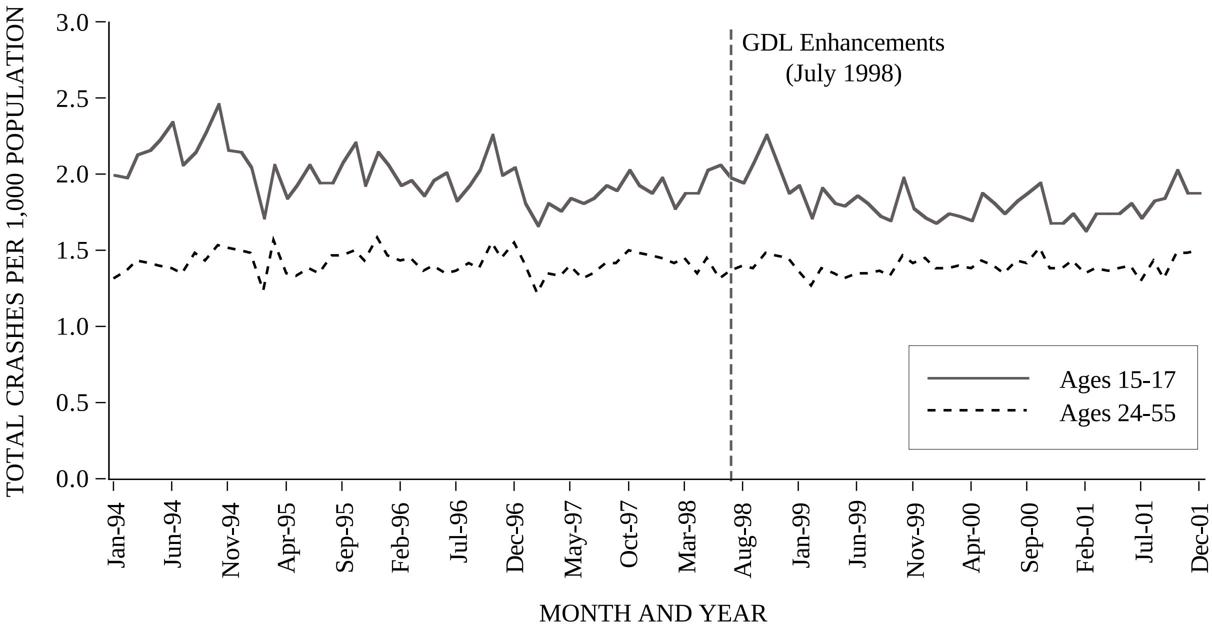


Figure 2. Monthly total crashes per 1,000 population for 15-17-year-olds and 24-55-year-olds during January 1994 through December 2001 by age of youngest driver involved.

The teen and adult series also evidence a seasonal pattern of data corresponding to yearly cycles, meaning that points 12 months apart are correlated and the series changed level within annual cycles. The lowest crash rates tended to occur in January and February, and the highest rates generally occurred between September and December. The average teen crash rate was 1.93 (SD = 0.17), and extreme values were 1.64 for February 2001 and 2.47 for October 1994. The average rate for adults was 1.41 (SD = 0.07), about 27% lower than the teen average, and extreme values were a low of 1.22 for February 1997 and a high of 2.49 for December 1995.

Table 1 presents the model statistics for the teen and adult univariate series and the multivariate teen series wherein the adult crash series was used to control for variability in the teen series. To reduce any bias associated with the transition effect discussed in the Methods section, additional parameters were entered into the multivariate model to represent behavior in the crash rates during the 6 months preceding and 6 months following the program start date. In these models, the intervention was made to start 6 months after the July 1998 formal start date of the program (i.e., January 1999).

For simplicity, model diagnostic statistics (e.g., Ljung-Box Q and residual mean square error) are not shown. All final models chosen met the common criteria for acceptability and were judged to be the most parsimonious and to give the best fit to the data of all models considered. The transition parameters were kept in the models regardless of their level of statistical significance, while all other parameters were evaluated using an alpha level of .05, two-tailed.

Table 1

Total Crash Rate Model Statistics for Gradual-Permanent, Sudden-Temporary, and Sudden-Permanent Interventions

Intervention	Model component	Parameter	Lag	Estimate	t
	Teen univariate				
Gradual-permanent[a]	Intervention	ω	0	0.0919	1.53
		δ	1	-0.8825	-7.26*
	Noise	MA	1	0.4482	4.56*
		MA	12	0.7074	8.22*
Sudden-temporary[a]	Intervention	ω	0	0.0553	1.46
		δ	1	-0.8390	-4.52*
	Noise	MA	1	0.4621	4.68*
		MA	12	0.6127	6.53*
Sudden-permanent[a]	Intervention	ω	0	0.0223	0.27
	Noise	MA	1	0.4588	4.63*
		MA	12	0.6997	8.45*
	Adult univariate				
Gradual-permanent[b]	Intervention	ω	0	-0.0360	-1.83
		δ	1	-1.0000	-37.89*
	Noise	MA	12	0.6903	7.87*
Sudden-temporary[b]	Intervention	ω	0	0.0212	0.41
		δ	1	-0.7116	-0.34
	Noise	MA	12	0.7073	8.25*
Sudden-permanent[b]	Intervention	ω	0	-0.0308	-2.59*
	Noise	MA	12	0.7340	9.07*
	Teen multivariate July 1998 intervention point				
Gradual-permanent[a]	Intervention	ω	0	-0.0046	-0.07
		δ	1	-0.3013	-0.02
	Covariate	β	0	1.0081	8.42*
	Noise	MA	1	0.4221	3.97*
		MA	12	0.6041	6.27*
Sudden-temporary[a]	Intervention	ω	0	-0.0126	-0.20
		δ	1	0.0182	0.00
	Covariate	β	0	1.0044	7.80*
	Noise	MA	1	0.4173	3.91*
		MA	12	0.6026	6.30*
Sudden-permanent[a]	Intervention	ω	0	0.0013	0.02
	Covariate	β	0	1.0073	8.42*
	Noise	MA	1	0.4224	3.99*
		MA	12	0.6060	6.34*
	January 1999 intervention point				
Gradual-permanent[a]	Intervention	ω	0	0.1720	1.65
		δ	1	-0.5303	-1.78
	Covariate	β	0	0.9900	8.49*
	Noise	MA	1	0.4233	3.89*
		MA	12	0.6106	6.17*
	January 98-June 98 Transition		0	0.1058	1.92
	July 98-December 98 Transition		0	0.0762	1.35
Sudden-temporary[a]	Intervention	ω	0	0.2305	3.08*
		δ	1	0.7630	5.68*
	Covariate	β	0	1.0219	8.03*
	Noise	MA	1	0.6006	5.97*
		MA	12	0.6008	6.15*
	January 98-June 98 Transition		0	0.1261	2.70*
	July 98-December 98 Transition		0	0.1583	2.67*
Sudden-permanent[a]	Intervention	ω	0	0.1557	1.45
	Covariate	β	0	1.0029	8.44*
	Noise	MA	1	0.4446	4.22*
		MA	12	0.6115	6.30*
	January 98-June 98 Transition		0	0.1117	1.92
	July 98-December 98 Transition		0	0.1170	1.39

[a]Models included differencing at lags 1 and 12 to produce stationary residuals. [b]Differenced at lag 12.
*$p < .05$, two-tailed.

The only statistically significant intervention component in the models that did not include transition effect components was the sudden-permanent effect in the univariate model for the 24-55-year-old total crash series (ω = -0.0308, t = -2.59), indicating an average monthly reduction of 0.0308 crashes per 1,000 24-55-year-olds. This represents about a 2.17% decrease in the average adult crash rate after implementation of the GDL enhancements, which equals 484 fewer crashes per month, or about 5,811 crashes saved per year.

When the 6-month transition components were included in the multivariate model, a significant sudden-temporary effect was found, with $\omega = 0.2305$ ($t = 3.08$) and $\delta = 0.7630$ ($t = 5.68$). This represents an increase of 0.2305 crashes per 1,000 15-17-year-olds the first month after the January 1999 intervention date (an 11.51% increase), with smaller monthly increases occurring until the series level returned to its pre-intervention level. The total one-time increased crash volume displacement is equal to $\frac{\omega}{1-\delta}$ or 0.9726 crashes per 1,000 capita. Given that the average monthly population of 15-17-year-olds from January 1999 to December 2001 was 1,455,160, this translates into a one-time cost of about 1,415 additional total crashes.

In summary, neither the univariate nor multivariate teen analyses found a statistically significant permanent change in the 15-17-year-old crash rates after the enhancements were introduced. However, a sudden-temporary increase in crashes occurred in the multivariate 15-17-year-old series after transition components for the 6 months before and 6 months after the program start date were added to the model, moving the intervention point forward to January 1999. This measured increase could be due to a rise in crash rates due to the influx of teen drivers that continued for some time beyond the transition periods included in the model.

Overall Fatal/Injury Crash Analyses

Monthly fatal/injury crashes per 1,000 population for 15-17-year-olds and 24-55-year-olds are plotted in Figure 3. The vertical line in the figure again indicates the implementation of the GDL enhancements in July 1998.

Both series are very similar in pattern to the total crash rate series, as would be expected given that fatal/injury crashes are a subset of total crashes. The rates for both groups, but particularly those for teens, appear to have generally steadily declined during the period of January 1994 to December 2001. The teen series again appears to have temporarily increased in the 6-month periods before and after the July 1998 program implementation date. In general, the crash rate for each group was lowest during the first few months of each year, gradually increased until September or October, and then dropped. The robust overall downward trend in the teen series strongly supports the analytical strategy used here to evaluate intervention effects only after removing seasonality and trend in the data.

The average teen fatal/injury crash rate was 0.82 (SD = 0.10), about 1.37 times the overall average rate of 0.60 (SD = 0.04) for adults. Extreme values for teens were 0.65 for February 2001 and 1.13 for October 1994. The highest rate for adults was 0.69 for October 1994, and the lowest rate was 0.51 for February 1999.

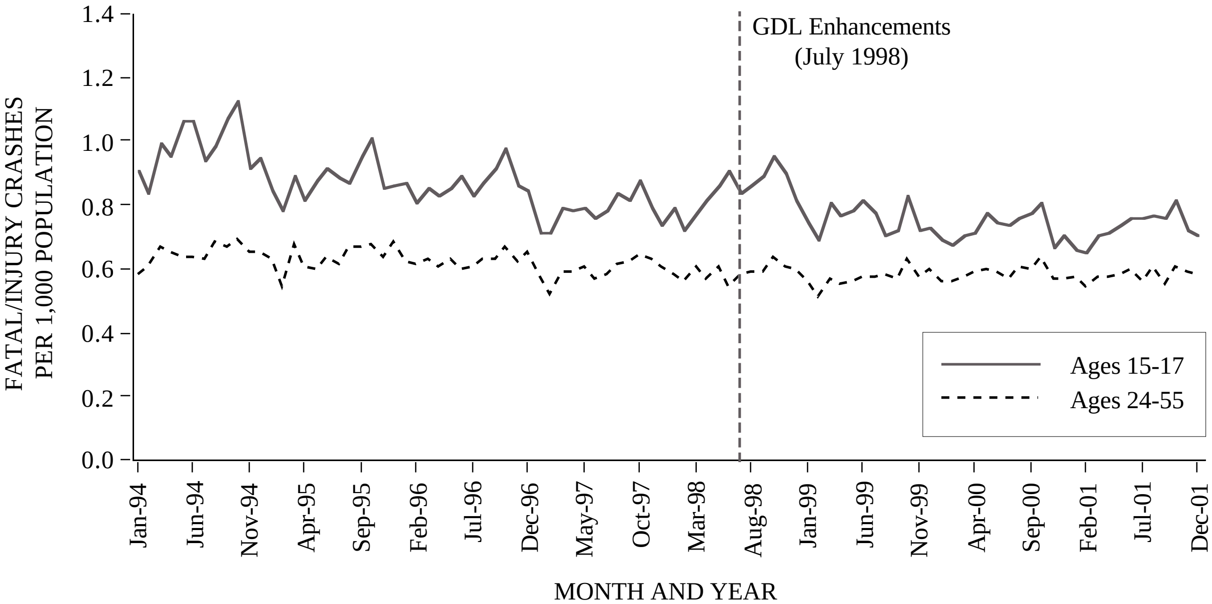


Figure 3. Monthly fatal/injury crashes per 1,000 population for 15-17-year-olds and 24-55-year-olds during January 1994 through December 2001 by age of youngest driver involved.

Table 2 presents the model statistics for each type of intervention effect for the teen and adult univariate series and the multivariate teen series wherein the adult crash rates were used to control for extraneous variability in the teen crash series. The multivariate model was again also evaluated using additional parameters to account for transitional behavior in the series 6-months before and after the formal start date. A January 1999 intervention date (6-months after the actual program implementation date) was used for this multivariate analysis. The statistical significance of all parameters was determined using an alpha level of .05, but the transition parameters were kept in the models regardless of their level of statistical significance.

The estimate of ω was not statistically significant for any of the series or types of intervention effects. Therefore, the null hypothesis of no intervention effect on fatal/injury crashes was accepted for all the analyses. Results of the multivariate analyses including transition components representing 6 months before and 6 months after the July 1998 start date to remove any bias associated with the transition effect also did not indicate a significant change in the teen fatal/injury crash series. Specifically, no sudden-temporary increase in fatal/injury crashes at the January 1999 intervention date was found, which was not consistent with the effect found for total crashes. In summary, the results do not suggest that the July 1998 enhancements were associated with any temporary or permanent changes in the fatal/injury crash rates of 15-17-year-olds, even after controlling for extraneous variability shared with the adult series, adding parameters to remove bias associated with the transition effect, and moving the intervention point 6-months ahead to January 1999.

Table 2

Fatal/Injury Crash Rate Model Statistics for Gradual-Permanent, Sudden-Temporary, and Sudden-Permanent Interventions

Intervention	Model component	Parameter	Lag	Estimate	t
		Teen univariate			
Gradual-permanent	Intervention	ω	0	-0.0105	-0.27
		δ	1	0.5705	0.29
	Noise	MA	1	0.4988	5.08*
		MA	12	0.5693	6.13*
Sudden-temporary	Intervention	ω	0	-0.0188	-0.52
		δ	1	0.3708	0.18
	Noise	MA	1	0.5004	5.17*
		MA	12	0.5636	5.93*
Sudden-permanent	Intervention	ω	0	0.0007	0.02
	Noise	MA	1	0.5103	5.19*
		MA	12	0.5763	5.64*
		Adult univariate			
Gradual-permanent	Intervention	ω	0	0.0106	0.50
		δ	1	-0.7726	-0.64
	Noise	MA	1	0.6261	7.20*
		MA	12	0.5919	6.18*
Sudden-temporary	Intervention	ω	0	0.0114	0.80
		δ	1	-0.6529	-1.65
	Noise	MA	1	0.6725	7.92*
		MA	12	0.6168	5.93*
Sudden-permanent	Intervention	ω	0	0.0023	0.13
	Noise	MA	1	0.6234	7.13*
		MA	12	0.5930	6.32*
		Teen multivariate			
		July 1998 intervention point			
Gradual-permanent	Intervention	ω	0	-0.0047	-0.12
		δ	1	-0.4956	-0.05
	Covariate	β	0	0.4569	2.40*
	Noise	MA	1	0.5340	5.34*
		MA	12	0.5632	5.96*
Sudden-temporary	Intervention	ω	0	-0.0293	-0.84
		δ	1	0.3476	0.26
	Covariate	β	0	0.4697	2.29*
	Noise	MA	1	0.4778	4.85*
		MA	12	0.5247	5.35*
Sudden-permanent	Intervention	ω	0	-0.0059	-0.17
	Covariate	β	0	0.4421	2.34*
	Noise	MA	1	0.5124	5.03*
		MA	12	0.5223	5.35*
		January 1999 intervention point			
Gradual-permanent	Intervention	ω	0	0.0543	0.95
		δ	1	-0.1436	-0.20
	Covariate	β	0	0.4024	2.23*
	Noise	MA	1	0.6182	6.47*
		MA	12	0.4981	4.85*
	January 98-June 98 Transition		0	0.0809	2.78*
	July 98-December 98 Transition		0	0.0900	2.24*
Sudden-temporary	Intervention	ω	0	0.0591	1.43
		δ	1	0.8318	2.91*
	Covariate	β	0	0.4005	2.04*
	Noise	MA	1	0.6199	6.54*
		MA	12	0.4979	4.83*
	January 98-June 98 Transition		0	0.0791	3.02*
	July 98-December 98 Transition		0	0.0849	2.71*
Sudden-permanent	Intervention	ω	0	0.0503	0.95
	Covariate	δ	0	0.4032	2.24*
	Noise	MA	1	0.6185	6.48*
		MA	12	0.4921	4.88*
	January 98-June 98 Transition		0	0.0814	2.79*
	July 98-December 98 Transition		0	0.0897	2.23*

Note. All models included differencing at lags 1 and 12 to produce stationary residuals.
$^{*}p < .05$, two-tailed.

Nighttime Total Crash Analyses

Monthly nighttime (12:00-5:00 a.m.) total crashes per 1,000 15-17-year-olds are plotted in Figure 4. The teen crash series suggests that nighttime crashes were the highest during the Summer months (June-August) when teens were out of school. The rates appear to have declined up until around the time the GDL enhancements were enacted and then leveled out for about a 1-year period. One-year after the intervention point, the teen rates appear to have declined again. The average teen nighttime total crash rate was 0.09 (*SD* = 0.02). Extreme values were 0.06 for January 2000 and 0.15 for August 1994.

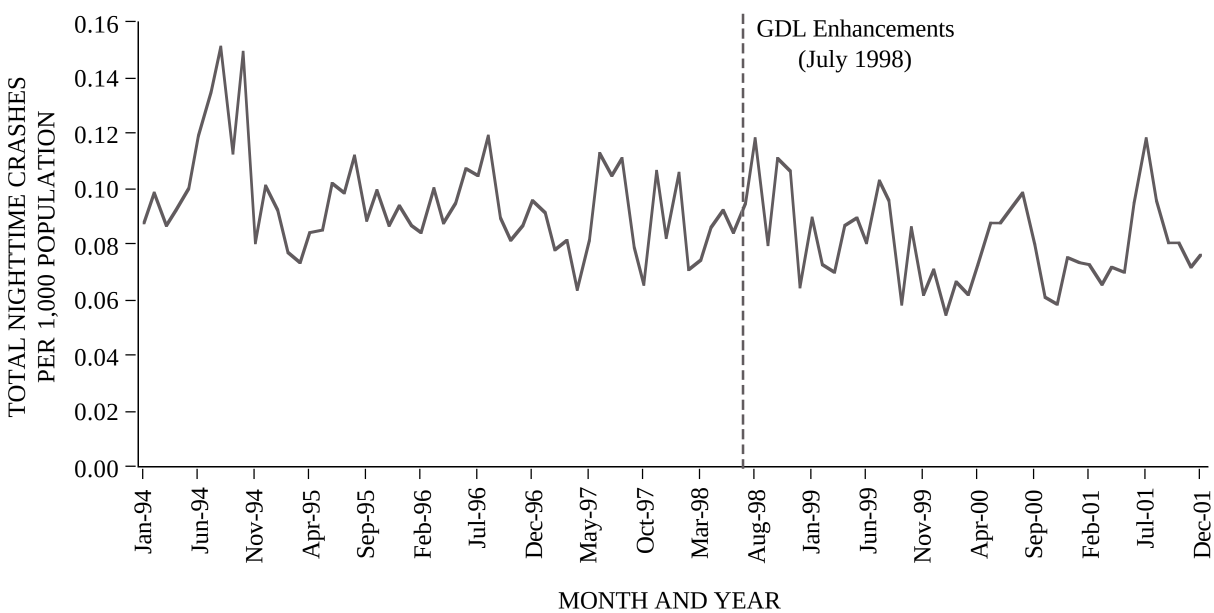


Figure 4. Monthly total nighttime crashes per 1,000 15-17-year-olds during January 1994 through December 2001 by age of youngest driver involved.

To estimate the impact of the GDL enhancements (particularly the nighttime driving restriction) on nighttime crash rates, the crashes represented in Figure 4 were evaluated as monthly proportions of 15-17-year-old total crashes. These monthly nighttime crash proportions are shown in Figure 5. The proportion of total teen crashes occurring during nighttime hours appears to have declined very slowly throughout the time series period, and the highest proportions again occur during the Summer months (June-August). The proportion representation of nighttime crashes for teen drivers ranged from 0.0032 of total crashes for October 2000 to 0.0700 for August 1994, with a mean representation of 0.0464 (*SD* = 0.0080).

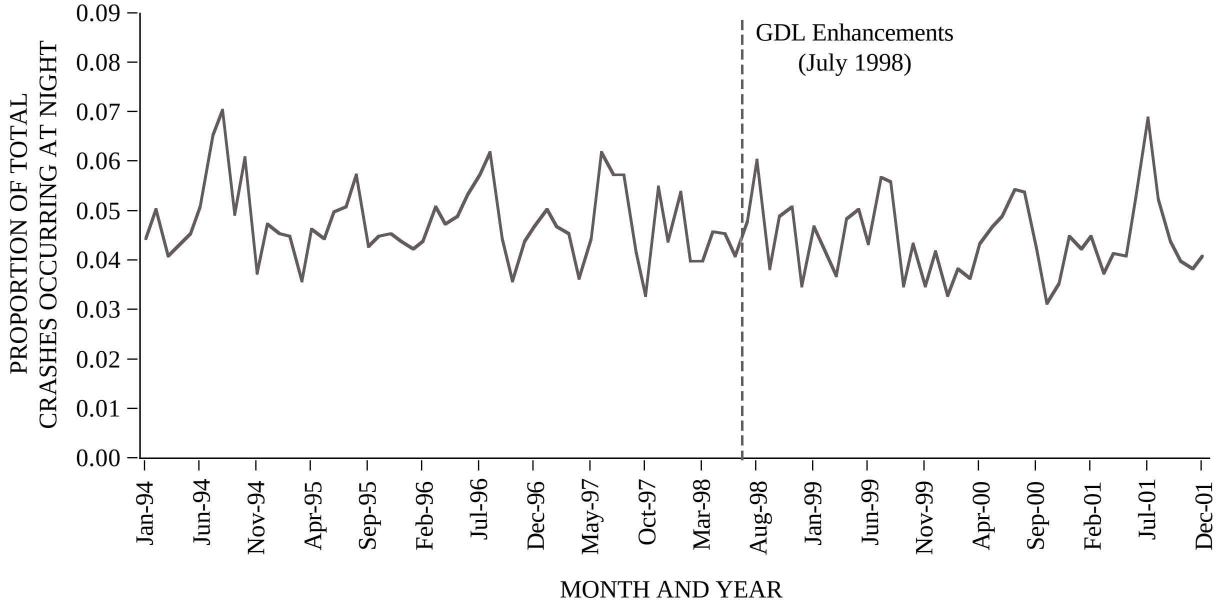


Figure 5. Proportion of monthly total crashes occurring during 12:00-5:00 a.m. for 15-17-year-olds during January 1994 through December 2001 by age of youngest driver involved.

Table 3 presents the univariate model statistics for each type of intervention effect evaluated for the teen nighttime proportion total crash series. The statistical significance of all parameters was again determined using an alpha level of .05. The three types of interventions were evaluated for three different sets of analyses presented in the table. The first set of analyses was calculated using the actual July 1998 implementation date as the intervention point for the models. To account for the transition effect, the second set of analyses included two transition components (6 months before and 6 months after the actual implementation date) to account for the increase in 16-17-year-old licensees around the time the GDL enhancements were implemented. For these analyses, the intervention date used was January 1999, which is 6 months after the GDL enhancements were actually implemented. The third set of analyses included these two 6-month transition components, plus an additional 6-month transition component, extending the intervention date by 1 year (to July 1999). This was done because no 16-17-year-olds would be subject to the nighttime restriction until at least 6 months after the implementation date due to the mandatory 6-month instruction permit period, and the additional 6 months allows for additional time for a reasonable number of teen drivers to be subject to the restriction. The transition parameters were kept in the models regardless of their level of statistical significance, while all other parameters were evaluated using an alpha level of .05, two-tailed.

Table 3

Total Nighttime Crash Proportion Model Statistics for Gradual-Permanent, Sudden-Temporary, and Sudden-Permanent Interventions

Intervention	Model component	Parameter	Lag	Estimate	t
		July 1998 Intervention Point			
Gradual-permanent	Intervention	ω	0	-0.0050	-1.72
		δ	1	-0.7419	-1.28
	Noise	MA	12	0.5068	4.70*
Sudden-temporary	Intervention	ω	0	-0.0094	-1.64
		δ	1	-0.4990	-0.98
	Noise	MA	12	0.4402	4.29*
Sudden-permanent	Intervention	ω	0	-0.0024	-1.37
	Noise	MA	12	0.4985	4.73*
		January 1999 intervention point			
Gradual-permanent	Intervention	ω	0	-0.0008	-0.50
		δ	1	0.8160	2.02*
	Noise	MA	12	0.5018	4.95*
	January 98-June 98 Transition		0	-0.0026	-1.03
	July 98-December 98 Transition		0	-0.0020	-0.76
Sudden-temporary	Intervention	ω	0	0.0025	0.41
		δ	1	0.2176	0.12
	Noise	MA	12	0.4288	4.00*
	January 98-June 98 Transition		0	-0.0010	-0.40
	July 98-December 98 Transition		0	0.003	0.13
Sudden-permanent	Intervention	ω	0	-0.0036	-1.81
	Noise	MA	12	0.4863	4.67*
	January 98-June 98 Transition		0	-0.0028	-1.11
	July 98-December 98 Transition		0	-0.0016	-0.63
		July 1999 intervention point			
Gradual-permanent	Intervention	ω	0	-0.0073	-2.18*
		δ	1	-0.9883	-2.07*
	Noise	MA	12	0.5085	5.06*
	January 98-June 98 Transition		0	-0.0023	-0.89
	July 98-December 98 Transition		0	-0.0019	-0.73
	January 99-June 99 Transition		0	-0.0015	-0.54
Sudden-temporary	Intervention	ω	0	0.0014	0.23
		δ	1	-0.3172	-0.07
	Noise	MA	12	0.4844	4.87*
	January 98-June 98 Transition		0	-0.0009	-0.34
	July 98-December 98 Transition		0	0.0000	0.00
	January 99-June 99 Transition		0	0.0008	0.30
Sudden-permanent	Intervention	ω	0	-0.0044	-2.12*
	Noise	MA	12	0.5003	4.91*
	January 98-June 98 Transition		0	-0.0025	-0.95
	July 98-December 98 Transition		0	-0.0020	-0.79
	January 99-June 99 Transition		0	-0.0017	-0.62

Note. All models included differencing at lag 12 to produce stationary residuals.
$^*p < .05$, two-tailed.

The estimate of ω was not statistically significant for any of the intervention types for the July 1998 or January 1999 nighttime total crash proportion models. However, the estimate of ω was statistically significant for the gradual-permanent (ω = -0.0073) and sudden-permanent (ω = -0.0044) models using the July 1999 implementation date. The gradual-permanent effect hypothesis was rejected because the δ parameter was negative, indicating an unstable effect. The sudden-permanent effect (ω = -0.0044) equals a 9.27% drop from the 0.0475 average proportional series level before the July

1999 intervention date. This represents a total monthly savings of 0.0087 crashes per 1,000 15-17-year-olds. Based on the average monthly population of 15-17-year-olds from July 1999 to December 2001 of 1,461,604, this amounts to about 13 crashes saved per month or 153 crashes saved annually, which is only a 0.44% reduction in total per capita crashes. This crash savings estimate is based on an assumption that the GDL night driving restriction did not increase daytime crashes.

Nighttime Fatal/Injury Crash Analyses

Monthly fatal/injury nighttime (12:00-5:00 a.m.) crashes per 1,000 15-17-year-olds are plotted in Figure 6. The fatal/injury crash series again suggests that the highest nighttime crash rate for teens was during the Summer months (June-August). However, October also tended to have a high nighttime fatal/injury teen crash rate, although this was not the case for nighttime total crashes. The rates appear to have declined until around April 2000 and then leveled. The average teen nighttime fatal/injury crash rate was 0.04 (*SD* = 0.01). Extreme low values for teens were 0.02 for February 1997, 1998, and 2000, and October 2000. The highest fatal/injury nighttime rate for teens was 0.08 for August and October 1994.

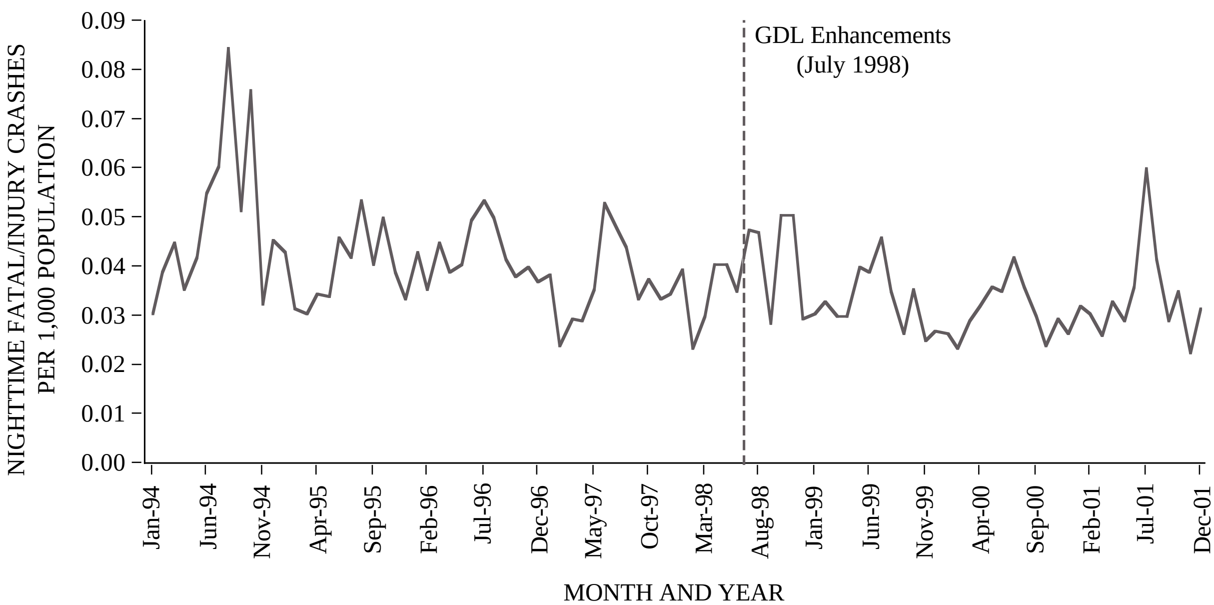


Figure 6. Monthly fatal/injury nighttime crashes per 1,000 15-17-year-olds during January 1994 through December 2001 by age of youngest driver involved.

The impact of the nighttime restriction was estimated based on an analysis of the proportion of fatal/injury crashes that occurred during the night curfew hours. The proportions of 15-17-year-old fatal/injury crashes occurring at nighttime (12:00-5:00 a.m.) each month are shown in Figure 7. Note the two extreme outlying proportions for August 1994 and July 2001.

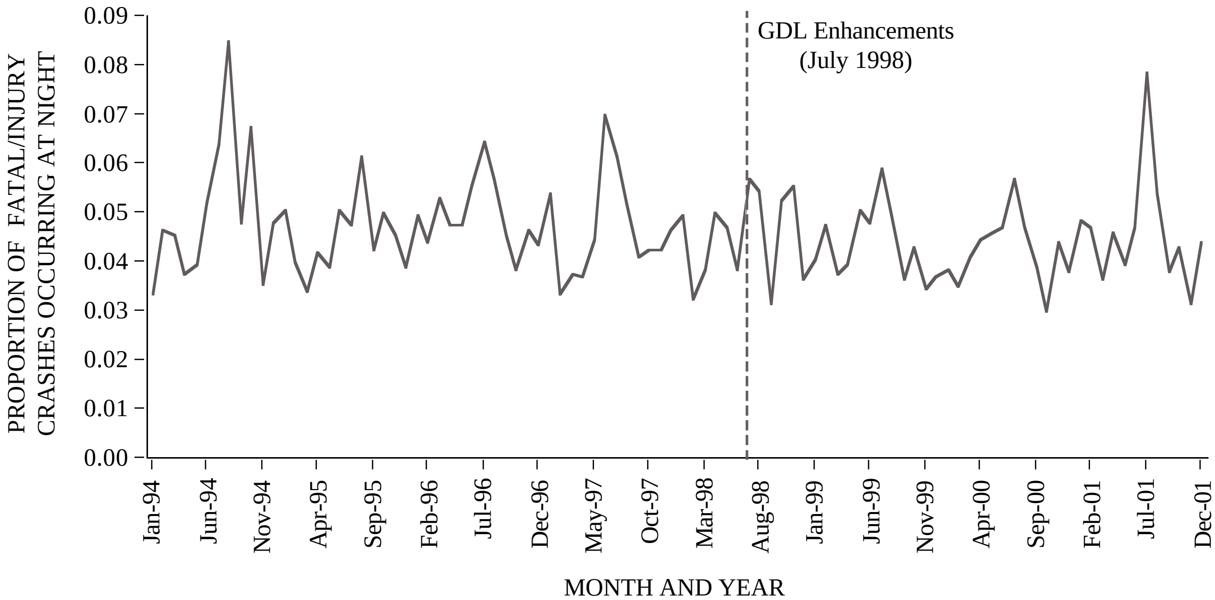


Figure 7. Proportion of monthly fatal/injury crashes occurring during 12:00-5:00 a.m. for 15-17-year-olds during January 1994 through December 2001 by age of youngest driver involved.

The proportion of fatal/injury teen crashes occurring at night appears to decline very slowly during January 1994 to around September 2000, at which point it appears to increase. The highest proportions again occur during June through August. Nighttime fatal/injury crashes ranged from 0.0030 of all fatal/injury crashes for October 2000 to 0.0850 for August 1994, with a mean proportion of 0.0460 (*SD* = 0.0100) of all fatal/injury crashes.

Table 4 presents the model statistics for each type of intervention effect for the teen fatal/injury nighttime proportion series. The statistical significance of all parameters was again determined using an alpha level of .05. Three different sets of analyses are again presented in the table. The first are based on the July 1998 intervention date, the second are based on a January 1999 intervention date, and the third are based on a July 1999 intervention date. The latter two sets of analyses again include parameters to reduce bias associated with the transition effect, and the final includes an additional 6-month transition component. In addition, two pulse parameters were used to model the extreme outliers for August 1994 and July 2001 in all models shown in Table 4. The transition and outlier pulse parameters were kept in the models regardless of their level of statistical significance, while all other parameters were evaluated using an alpha level of .05, two-tailed.

The estimate of ω was not statistically significant for any of the intervention types and intervention points for nighttime fatal/injury crash proportions. However, the estimate of $\omega = -0.0045$ was borderline statistically significant ($t = -1.94$) for the sudden-permanent intervention for the July 1999 (1-year-post implementation) series. This result suggests that there was a sudden 9.56% drop from the average 0.0471 prior series level in the proportion of nighttime fatal/injury crashes beginning 1-year after the GDL program implementation date. This equals a monthly savings of 0.0039 fatal/injury crashes per 1,000 15-17-year-olds, which is about 6 per month or 68 fatal/injury crashes annually. The decrease was not very large, however, translating into only a 0.45% decrease in all per capita fatal/injury crashes for 15-17-year-olds. Again, this crash savings estimate is based on an assumption that the GDL night driving restriction did not increase daytime crashes.

Table 4

Fatal/Injury Nighttime Crash Proportion Model Statistics for Gradual-Permanent, Sudden-Temporary, and Sudden-Permanent Interventions

Intervention	Model component	Parameter	Lag	Estimate	*t*
	July 1998 intervention point				
Gradual-permanent	Intervention	ω	0	-0.0045	-1.34
		δ	1	-0.8068	-1.17
	Noise	MA	12	0.5666	6.04*
	August 1994 outlier		0	0.0271	4.10*
	July 2001 outlier		0	0.0209	2.61*
Sudden-temporary	Intervention	ω	0	-0.0045	-0.92
		δ	1	-0.5553	-1.08
	Noise	MA	12	0.5592	5.95*
	August 1994 outlier		0	0.0276	4.28*
	July 2001 outlier		0	0.0204	2.61*
Sudden-permanent	Intervention	ω	0	-0.0024	-1.20
	Noise	MA	12	0.5711	6.06*
	August 1994 outlier		0	0.0269	4.05*
	July 2001 outlier		0	0.0212	2.64*
	January 1999 intervention point				
Gradual-permanent	Intervention	ω	0	-0.0010	-0.45
		δ	1	0.7776	1.22
	Noise	MA	12	0.5585	5.92*
	January 98-June 98 Transition		0	-0.0034	-1.12
	July 98-December 98 Transition		0	-0.0003	-0.09
	August 1994 outlier		0	0.0268	4.06*
	July 2001 outlier		0	0.0223	2.80*
Sudden-temporary	Intervention	ω	0	-0.0077	-1.12
		δ	1	-0.5208	-0.73
	Noise	MA	12	0.5514	5.81*
	January 98-June 98 Transition		0	-0.0021	-0.75
	July 98-December 98 Transition		0	0.0018	0.66
	August 1994 outlier		0	0.0272	4.26*
	July 2001 outlier		0	0.0212	2.75*
Sudden-permanent	Intervention	ω	0	-0.0040	-1.83
	Noise	MA	12	0.5533	5.95*
	January 98-June 98 Transition		0	-0.0037	-1.20
	July 98-December 98 Transition		0	-0.0002	-0.05
	August 1994 outlier		0	0.0269	4.08*
	July 2001 outlier		0	0.0220	2.78*
	July 1999 intervention point				
Gradual-permanent	Intervention	ω	0	-0.0032	-0.73
		δ	1	0.3269	0.38
	Noise	MA	12	0.5544	5.91*
	January 98-June 98 Transition		0	-0.0035	-1.14
	July 98-December 98 Transition		0	-0.0004	-0.13
	January 99-June 99 Transition		0	-0.0026	-0.81
	August 1994 outlier		0	0.0268	4.09*
	July 2001 outlier		0	0.0226	2.80*
Sudden-temporary	Intervention	ω	0	0.0016	0.23

Table 4 (continued)

Intervention	Model component	Parameter	Lag	Estimate	t
		δ	1	-0.5438	-0.17
	Noise	MA	12	0.5539	5.82*
	January 98-June 98 Transition		0	-0.0021	-0.71
	July 98-December 98 Transition		0	0.0017	0.61
	January 99-June 99 Transition		0	-0.0003	-0.10
	August 1994 outlier		0	0.0273	4.20*
	July 2001 outlier		0	0.0215	2.68*
Sudden-permanent	Intervention	ω	0	-0.0045	-1.94
	Noise	MA	12	0.5563	5.96*
	January 98-June 98 Transition		0	-0.0034	-1.12
	July 98-December 98 Transition		0	-0.0004	-0.13
	January 99-June 99 Transition		0	-0.0025	-0.79
	August 1994 outlier		0	0.0269	4.10*
	July 2001 outlier		0	0.0222	2.80*

Note. All models included differencing at lag 12 to produce stationary residuals.
*$p < .05$, two-tailed.

Total Teen Passenger Crash Analyses

The monthly total crashes per 1,000 15-17-year-olds involving a passenger under the age of 20 are shown in Figure 8 for the period between January 1994 through December 2001.

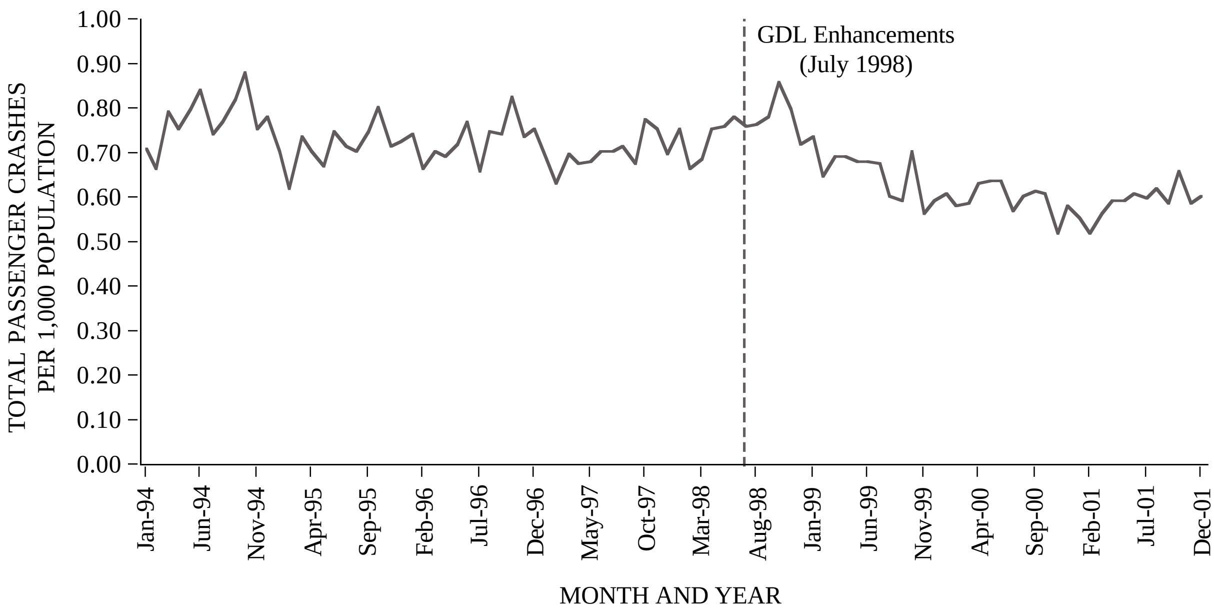


Figure 8. Monthly total crashes with a passenger under age 20 per 1,000 15-17-year-olds during January 1994 through December 2001 by age of youngest driver involved.

The teen passenger total crash rates appear to be relatively flat before the GDL enhancements, increase immediately afterward, decrease starting about a year later, and then increase again during the last year. The mean teen total passenger crash rate for the entire period shown in the figure was 0.6922 per 1,000 capita (*SD* = 0.0786).

The impact of the passenger restriction was estimated based on an analysis of the proportion of total teen crashes that involved a passenger under the age of 20. The proportion of teen passenger crashes out of all teen crashes is plotted in Figure 9 for the period January 1994 through December 2001. The proportion representation of teen passenger crashes also appears to have declined about a year or so after the GDL enhancements were implemented. The mean total crash proportion for teens during this period was 0.3590 (*SD* = 0.0212).

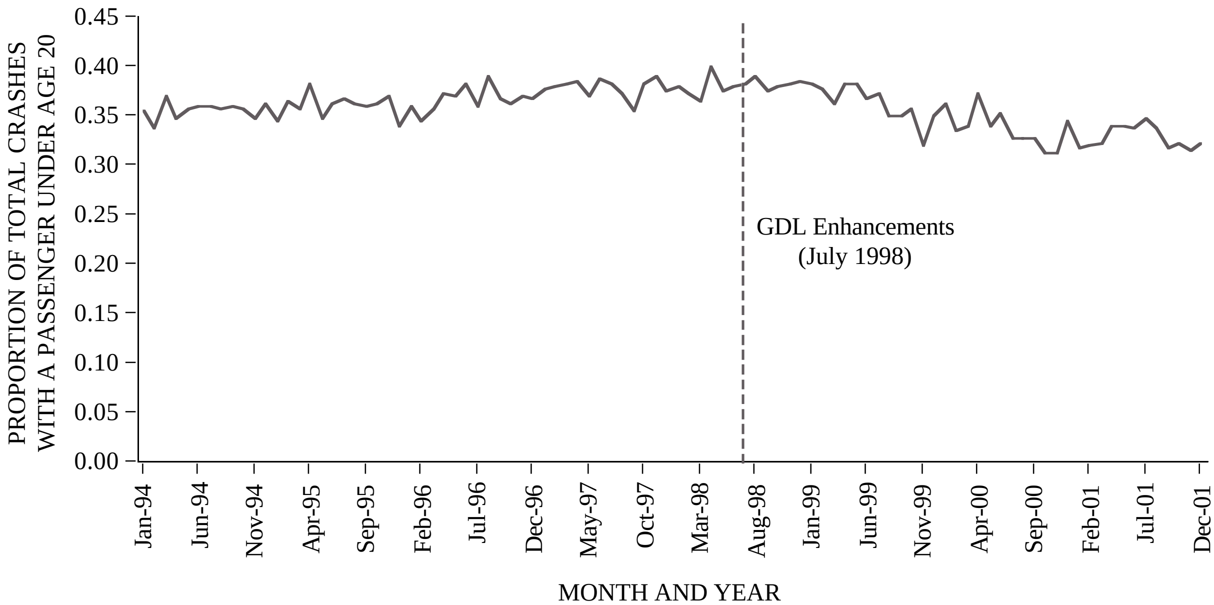


Figure 9. Proportion of monthly 15-17-year-old total crashes with a passenger under age 20 during January 1994 through December 2001 by age of youngest driver involved.

The gradual-permanent, sudden-temporary, and sudden-permanent intervention types for these data were modeled using three different intervention points: July 1998, January 1999, and July 1999. The first intervention point represented the actual date the passenger restriction was implemented (although no teens driving at that time would have been subject to the restriction due to the 6-month instruction permit period). The second 6-month subsequent time point was used to enable 6-month pre- and 6-month post-transition components to be embedded in the model to remove the transition effects of having an large increase in the number of teens licensed around the time of the GDL enhancements. The final 1-year subsequent time point was used to determine the effects of the passenger restriction after at least half a year's worth of teens were subject to the passenger restriction. The time series models for each of the intervention time points and intervention types are shown in Table 5. The transition parameters were kept in the models regardless of their level of statistical significance, while all other parameters were evaluated using an alpha level of .05, two-tailed.

Table 5

Total Teen Passenger Crash Proportion Model Statistics for Gradual-Permanent, Sudden-Temporary, and Sudden-Permanent Interventions

Intervention	Model component	Parameter	Lag	Estimate	*t*
	July 1998 intervention point				
Gradual-permanent	Intervention	ω	0	0.0043	0.33
		δ	1	-0.3365	-0.16
	Noise	MA	1	0.0805	8.50*
Sudden-temporary	Intervention	ω	0	0.0039	0.34
		δ	1	0.9655	0.57
	Noise	MA	1	0.6599	8.34*
Sudden-permanent	Intervention	ω	0	0.0024	0.25
	Noise	MA	1	0.6778	9.19*
	January 1999 intervention point				
Gradual-permanent	Intervention	ω	0	-0.0008	-0.05
		δ	1	0.5909	0.04
	Noise	MA	1	0.6901	9.20*
	January 98-June 98 Transition		0	0.0017	0.18
	July 98-December 98 Transition		0	0.0063	0.50
Sudden-temporary	Intervention	ω	0	0.0147	1.06
		δ	1	0.9054	2.05*
	Noise	MA	1	0.6876	8.89*
	January 98-June 98 Transition		0	0.0049	0.55
	July 98-December 98 Transition		0	0.0127	1.17
Sudden-permanent	Intervention	ω	0	-0.0049	-0.33
	Noise	MA	1	0.6943	9.42*
	January 98-June 98 Transition		0	0.0003	0.03
	July 98-December 98 Transition		0	0.0035	0.28
	July 1999 intervention point				
Gradual-permanent	Intervention	ω	0	0.0001	0.01
		δ	1	-0.8531	-0.01
	Noise	MA	1	0.7340	10.68*
	January 98-June 98 Transition		0	0.0020	0.23
	July 98-December 98 Transition		0	0.0065	0.56
	January 99-June 99 Transition		0	0.0012	0.09
Sudden-temporary	Intervention	ω	0	0.0192	1.51
		δ	1	-0.0558	-0.09
	Noise	MA	1	0.7012	9.49*
	January 98-June 98 Transition		0	0.0077	0.95
	July 98-December 98 Transition		0	0.0175	1.89
	January 99-June 99 Transition		0	0.0178	2.03*
Sudden-permanent	Intervention	ω	0	-0.0252	-1.91
	Noise	MA	1	0.7797	12.16*
	January 98-June 98 Transition		0	0.0010	0.12
	July 98-December 98 Transition		0	0.0044	0.43
	January 99-June 99 Transition		0	-0.0022	-0.18

Note. All models including differencing at lag 1 to produce stationary residuals.
$^*p < .05$, two-tailed.

As can be seen in the table, none of the ω parameters were statistically significant for any of the time periods, indicating no significant gradual or sudden decrease in the proportion of teen passenger crashes at the intervention point, 6-months afterward, or

1-year subsequent. However, the *t* value for the sudden-permanent model 1-year subsequent to the GDL enhancements (at which time about a half year's worth of teens would be subject to the passenger restriction) was borderline significant (ω = -0.0252, *t* = -1.91). This suggests the possibility that the proportion of passenger crashes dropped by 0.0252 or 6.82% from the January 1994 through June 1999 average proportion of 0.3692. This equates to an average monthly savings of 0.0501 passenger crashes per 1,000 15-17-year-olds, which is approximately 73 crashes per month or 878 crashes per year. This effect represents a 2.52% decrease in per capita total crashes (whether or not they involved a passenger under age 20). This crash savings estimate is based on an assumption that the GDL passenger restriction did not cause an increase in non-passenger crashes for the 15-17-year-old age group.

Fatal/Injury Teen Passenger Crash Analyses

The monthly fatal/injury crashes per 1,000 15-17-year-olds involving a passenger under age 20 are shown in Figure 10 for the period between January 1994 through December 2001. The mean fatal/injury passenger crash rate for teens during this period was 0.3709 (*SD* = 0.0556). The impact of the passenger restriction was again estimated based on an analysis of the proportion of fatal/injury teen crashes that involved a passenger under the age of 20. These proportions are shown in Figure 11 for the same time period. The mean fatal/injury teen passenger crash proportion during this period was 0.4491 (*SD* = 0.0278). The time series model estimates, again analyzed using the actual, 6-month post, and 1-year subsequent intervention points, are shown in Table 6. The transition parameters were again kept in the models regardless of their level of statistical significance, while all other parameters were evaluated using an alpha level of .05, two-tailed.

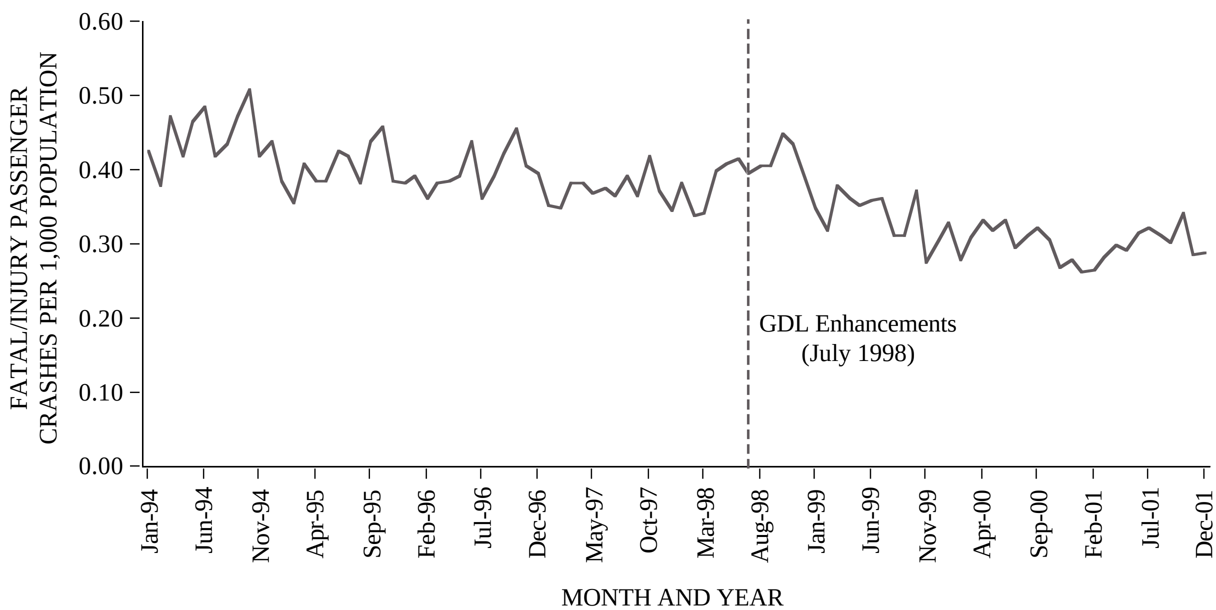


Figure 10. Monthly fatal/injury crashes with a passenger under age 20 per 1,000 15-17-year-olds during January 1994 through December 2001 by age of youngest driver involved.

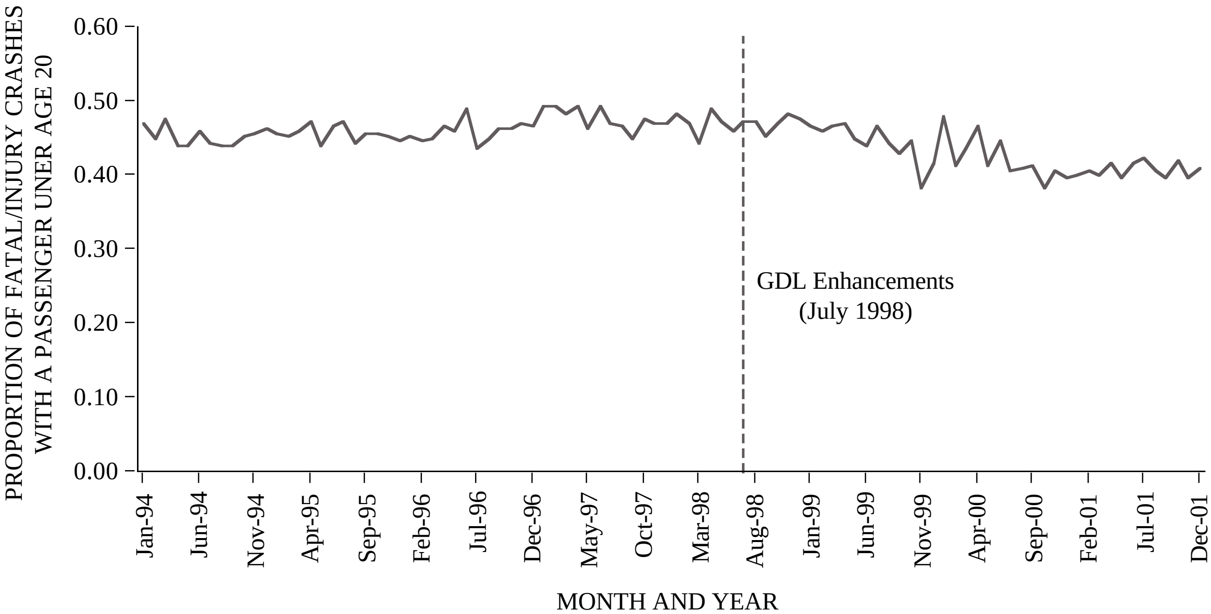


Figure 11. Proportion of monthly 15-17-year-old fatal/injury crashes with a passenger under age 20 during January 1994 through December 2001 by age of youngest driver involved.

Table 6

Fatal/Injury Teen Passenger Crash Proportion Model Statistics for Gradual-Permanent, Sudden-Temporary, and Sudden-Permanent Interventions

Intervention	Model component	Parameter	Lag	Estimate	*t*
		July 1998 intervention point			
Gradual-permanent	Intervention	ω	0	-0.0026	-1.94
		δ	1	0.9791	38.11*
	Noise	MA	1	0.8910	16.67*
		MA	3	-0.3943	-3.96*
Sudden-temporary	Intervention	ω	0	-0.0003	-0.31
		δ	1	-1.0724	-14.45*
	Noise	MA	1	0.7702	11.36*
		MA	3	-0.3941	-3.98*
Sudden-permanent	Intervention	ω	0	-0.0073	-0.63
	Noise	MA	1	0.7628	11.27*
		MA	3	-0.3821	-3.80*
		January 1999 intervention point			
Gradual-permanent	Intervention	ω	0	-0.0048	-2.29*
		δ	1	0.9374	27.97*
	Noise	MA	1	0.9107	19.53*
		MA	3	-0.3928	-3.99*
	January 98-June 98 Transition		0	-0.0023	-0.26
	July 98-December 98 Transition		0	-0.0028	-0.31
Sudden-temporary	Intervention	ω	0	0.0039	0.23
		δ	1	0.8407	0.32
	Noise	MA	1	0.7730	10.78*
		MA	3	-0.3548	-3.40*
	January 98-June 98 Transition		0	0.0024	0.22
	July 98-December 98 Transition		0	0.0063	0.47

Table 6 (continued)

Intervention	Model component	Parameter	Lag	Estimate	*t*
	January 1999 intervention point (continued)				
Sudden-permanent	Intervention	ω	0	-0.0228	-1.28
	Noise	MA	1	0.7771	11.45*
		MA	3	-0.3942	-3.87*
	January 98-June 98 Transition		0	-0.0066	-0.56
	July 98-December 98 Transition		0	-0.0104	-0.69
	July 1999 intervention point				
Gradual-permanent	Intervention	ω	0	-0.0100	-2.03*
		δ	1	0.8447	11.29*
	Noise	MA	1	0.9077	18.77*
		MA	3	-0.4228	-4.31*
	January 98-June 98 Transition		0	-0.0034	-0.37
	July 98-December 98 Transition		0	-0.0052	-0.50
	January 99-June 99 Transition		0	-0.0166	-1.49
Sudden-temporary	Intervention	ω	0	0.0189	1.25
		δ	1	0.6925	0.76
	Noise	MA	1	0.7925	12.58*
		MA	3	-0.3825	-3.78*
	January 98-June 98 Transition		0	0.0032	0.31
	July 98-December 98 Transition		0	0.0074	0.63
	January 99-June 99 Transition		0	0.0025	0.21
Sudden-permanent	Intervention	ω	0	-0.0244	-1.23
	Noise	MA	1	0.7864	11.18*
		MA	3	-0.3815	-3.82*
	January 98-June 98 Transition		0	-0.0064	-0.55
	July 98-December 98 Transition		0	-0.0101	-0.67
	January 99-June 99 Transition		0	-0.0214	-1.19

Note. All models included differencing at lag 1 to produce stationary residuals.
$^{*}p < .05$, two-tailed.

The gradual-permanent intervention model was statistically significant 6-months (ω = -0.0048, t = -2.29) and 1-year (ω = -0.0100, t = -2.03) post-implementation and approached significance (ω = -0.0026, t = -1.94) at the actual July 1998 intervention point. Given that no teenagers were actually under the passenger restriction for at least 6 months after the actual implementation date, and the fact that the July 1999 intervention model represents at least partial saturation of teens under the restriction and hence a more accurate representation of the true impact of the passenger restriction than the January 1999 intervention model, the estimation of series reductions in percentage representation of fatal/injury passenger crashes and fatal/injury crash savings are based on the July 1999 intervention model. This effect indicates that the proportion of fatal/injury passenger crashes decreased by 0.010 or 2.16% from the January 1994 through June 1999 average proportion of 0.4630 the first month after the July 1999 intervention date (a 1.0% decrease in all fatal/injury crashes). Larger monthly decreases occurred until the series reached a stable post-intervention level of 0.0644 fewer proportional passenger crashes per 1,000 capita (a 13.91% decrease in the proportional representation of passenger fatal/injury crashes). This equates to an average monthly savings of 0.0556 fatal/injury passenger crashes per 1,000 15-17-year-olds, or a 6.43% decrease in all 15-17-year-old fatal/injury crashes based on the 0.8644 pre-intervention level. Given that the average monthly population of 15-17-year olds from July 1999 to December 2001 was 1,461,604, this translates into about 81 fewer fatal/injury crashes per month, or 975 fewer fatal/injury crashes annually. Again, this crash savings estimate is based on an assumption that the GDL passenger restriction did not cause an increase in non-passenger crashes for the 15-17-year-old age group.

Total Crashes for 16-Year-Olds
Recall that analyses involving 16-year-olds as the youngest involved driver are considered to be conceptually less biased for purposes of evaluating the overall impact of the GDL enhancements, because of a shorter transition time period for the drivers in this age group to be completely under the new GDL program. Plots of total monthly crashes per 1,000 16-year-olds and 24-55-year-olds during the period of January 1994 through December 2001 are shown in Figure 12. The average total crash rate per 1,000 16-year-olds during this time period was 2.31 (SD = 0.30), which is 0.38 higher than the 15-17-year-old total crash rate analyzed earlier, and 1.64 times higher than the adult rate of 1.41.

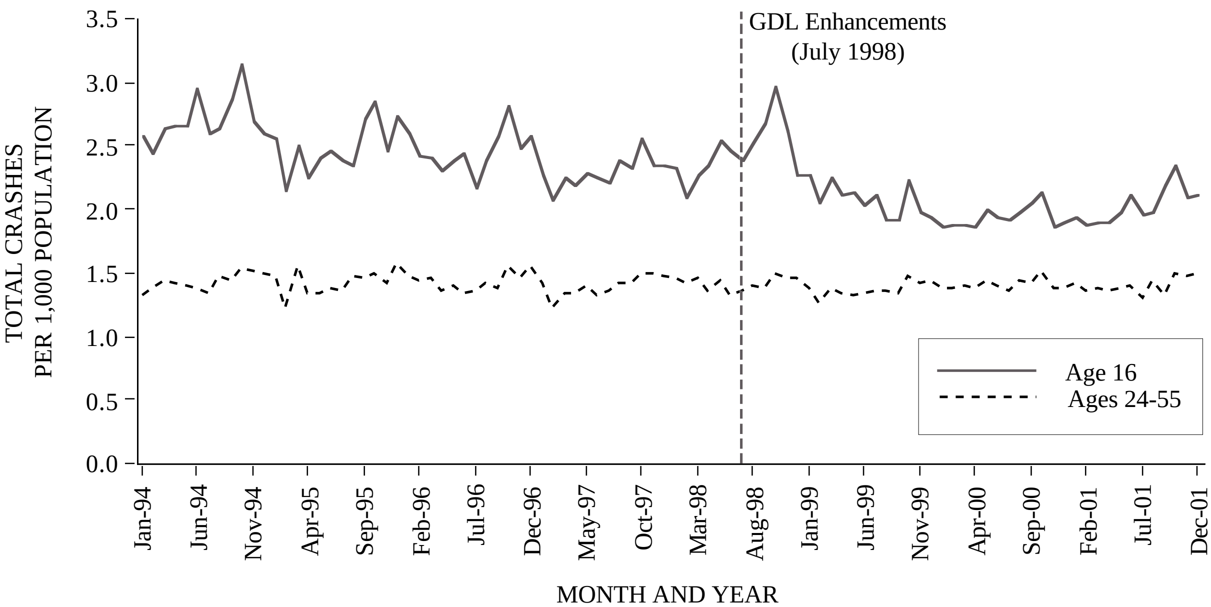


Figure 12. Monthly total crashes per 1,000 population for 16-year-olds and 24-55-year-olds during January 1994 through December 2001 by age of youngest driver involved.

The results of the time series analyses for the gradual-permanent, sudden-temporary, and sudden-permanent intervention types for the series for 16-year-olds, both with and without using the adult rate as a covariate, are shown in Table 7. Although any bias associated with the transition effects would be expected to be lower for 16-year-olds than for the analyses including 15-17-year-olds conducted earlier, the analyses for 16-year-olds were also conducted using two different possible intervention points, July 1998 and January 1999, in an attempt to remove any such effects. The transition parameters were kept in the models regardless of their level of statistical significance, while all other parameters were evaluated using an alpha level of .05, two-tailed. The adult univariate rates are not modeled here because they were modeled earlier.

Table 7

16-Year-Old Total Crash Rate Model Statistics for Gradual-Permanent, Sudden-Temporary, and Sudden-Permanent Interventions

Intervention	Model component	Parameter	Lag	Estimate	*t*
		Teen univariate			
Gradual-permanent	Intervention	ω	0	0.0494	0.41
		δ	1	0.6757	0.59
	Noise	MA	1	0.3978	3.89*
		MA	12	0.6543	7.22*
Sudden-temporary	Intervention	ω	0	-0.0497	-0.46
		δ	1	-0.2269	-0.11
	Noise	MA	1	0.4176	4.21*
		MA	12	0.6083	6.60*
Sudden-permanent	Intervention	ω	0	0.0480	0.43
	Noise	MA	1	0.4043	4.00*
		MA	12	0.6579	7.45*
		Teen multivariate			
		July 1998 intervention point			
Gradual-permanent	Intervention	ω	0	0.0687	0.74
		δ	1	0.3294	0.39
	Covariate	β	0	0.9323	4.88*
	Noise	MA	1	0.4027	3.89*
		MA	12	0.6171	6.69*
Sudden-temporary	Intervention	ω	0	-0.0881	-0.94
		δ	1	-0.3766	-0.43
	Covariate	β	0	0.9788	4.86*
	Noise	MA	1	0.3669	3.52*
		MA	12	0.6102	6.64*
Sudden-permanent	Intervention	ω	0	0.0316	0.32
	Covariate	β	0	0.9308	4.84*
	Noise	MA	1	0.3917	3.85*
		MA	12	0.6208	6.76*
		January 1999 intervention point			
Gradual-permanent	Intervention	ω	0	0.0975	1.22
		δ	1	-0.9125	-6.29*
	Covariate	β	0	0.9217	4.78*
	Noise	MA	1	0.4223	3.91*
		MA	12	0.6187	6.71*
	January 98-June 98 Transition		0	0.0651	0.85
	July 98-December 98 Transition		0	0.1112	1.26
Sudden-temporary	Intervention	ω	0	0.1311	0.89
		δ	1	0.6202	1.25
	Covariate	β	0	0.9494	4.62*
	Noise	MA	1	0.4570	4.15*
	January 98-June 98 Transition		0	0.0741	0.82
	July 98-December 98 Transition		0	0.1298	1.07
Sudden-permanent	Intervention	ω	0	0.0594	0.34
	Covariate	β	0	0.9181	4.72*
	Noise	MA	1	0.4382	4.16*
		MA	12	0.6254	6.68*
	January 98-June 98 Transition		0	0.0654	0.68
	July 98-December 98 Transition		0	0.1137	0.84

Note. All models included differencing at lags 1 and 12 to produce stationary residuals.
**p* < .05, two-tailed.

Consistent with the results found for the total crash series including all teens aged 15-17-years-old, the results for 16-year-olds did not indicate a significant permanent change in their total crash rates after the GDL enhancements either at the actual implementation date or 6-months subsequent. This was found even when the 24-55-year-old series was used to remove variability in the 16-year-old total crash rates. The only difference between these analyses and those for the 15-17-year-olds is that the 16-

year-old series did not experience a statistically significant temporary increase in total crash rates 6-months after the GDL program was implemented. This finding reinforces the conclusion that this temporary increase in total crashes for the 15-17-year-olds is really just an artifact of the transition effect.

Fatal/Injury Crashes for 16-Year-Olds

Plots of fatal/injury monthly crashes per 1,000 16-year-olds and 24-55-year-olds during January 1994 through December 2001 are shown in Figure 13. The average fatal/injury crash rate per 1,000 16-year-olds during this time period was 0.98 (SD = 0.16), which is 0.16 times higher than the 15-17-year-olds fatal/injury crash rate analyzed earlier, and 1.63 times higher than the adult fatal/injury per-capita rate of 0.60.

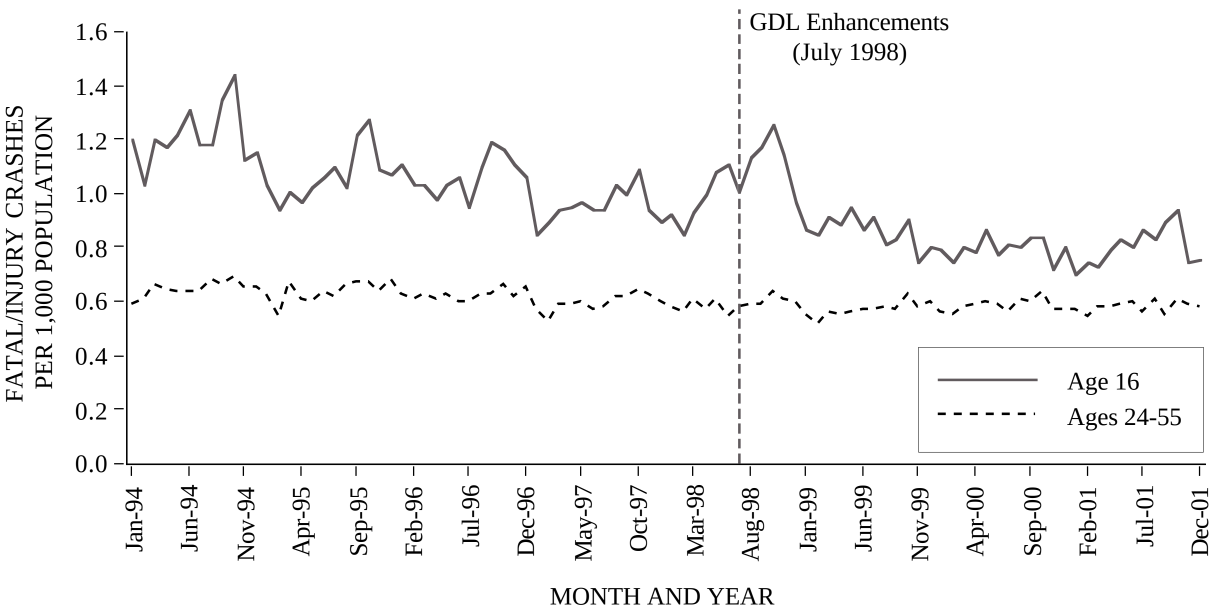


Figure 13. Monthly fatal/injury crashes per 1,000 population for 16-year-olds and 24-55-year-olds during January 1994 through December 2001 by age of youngest driver involved.

The time series analysis results for this series are shown in Table 8. The transition parameters were kept in the models regardless of their level of statistical significance, while all other parameters were evaluated using an alpha level of .05, two-tailed. Consistent with the analyses conducted for 15-17-year-olds, none of the intervention parameters were statistically significant for 16-year-old fatal/injury crashes at the actual July 1998 implementation date or 6-months subsequent, even after using the adult series as a covariate. This indicates that the program implementation was not associated with a statistically significant sudden or gradual change in the fatal/injury crash rates of 16-year-olds.

Table 8

16-Year-Old Fatal/Injury Crash Rate Model Statistics for Gradual-Permanent, Sudden-Temporary, and Sudden-Permanent Interventions

Intervention	Model component	Parameter	Lag	Estimate	t
		Teen univariate			
Gradual-permanent[a]	Intervention	ω	0	0.0220	0.48
		δ	1	0.1951	0.20
	Noise	MA	1	0.4492	4.30*
		MA	12	0.5620	5.80*
Sudden-temporary[a]	Intervention	ω	0	-0.0964	-1.81
		δ	1	-0.1449	-0.30
	Noise	MA	1	0.4070	4.00*
		MA	12	0.5789	6.06*
Sudden-permanent[a]	Intervention	ω	0	-0.0125	-0.21
	Noise	MA	1	0.4366	4.26*
		MA	12	0.5644	5.89*
		Teen multivariate			
		July 1998 intervention point			
Gradual-permanent[b]	Intervention	ω	0	0.0122	0.23
		δ	1	-0.3234	-0.17
	Covariate	β	0	1.2273	4.63*
	Noise	MA	1	0.4490	4.35*
Sudden-temporary[b]	Intervention	ω	0	-0.1093	-1.57
		δ	1	-0.0952	-0.15
	Covariate	β	0	1.2616	4.79*
	Noise	MA	1	0.3856	3.78*
Sudden-permanent[b]	Intervention	ω	0	-0.0256	-0.35
	Covariate	β	0	1.2442	4.69*
	Noise	MA	1	0.4386	4.45*
		January 1999 intervention point			
Gradual-permanent[b]	Intervention	ω	0	-0.1172	-0.98
		δ	1	-0.2868	-0.37
	Covariate	β	0	1.2630	4.69*
	Noise	MA	1	0.5478	5.70*
	January 98-June 98 Transition		0	0.0232	0.35
	July 98-December 98 Transition		0	0.0328	0.36
Sudden-temporary[b]	Intervention	ω	0	-0.0529	-0.64
		δ	1	0.1305	0.09
	Covariate	β	0	1.3654	4.97*
	Noise	MA	1	0.5062	4.94*
	January 98-June 98 Transition		0	0.0514	0.88
	July 98-December 98 Transition		0	0.0695	1.03
Sudden-permanent[b]	Intervention	ω	0	-0.1045	-0.92
	Covariate	β	0	1.2464	4.67*
	Noise	MA	1	0.5399	5.55*
	January 98-June 98 Transition		0	0.0222	0.33
	July 98-December 98 Transition		0	0.0292	0.31

[a]Models included differencing at lags 1 and 12 to produce stationary residuals. [b]Differenced at lag 1.
*$p < .05$, two-tailed.

Total and Fatal/Injury Crash Involvements

For the following analyses, series were created in which each crash incident was typically assigned multiple times, because most crashes involved two or more drivers. These analyses were conducted to determine if using crash involvement rates would yield results consistent with those from the analyses of total and fatal/injury crash rates based on the age of the youngest involved driver. Plots of total and fatal/injury monthly crashes per 1,000 population for 15-17-year-olds and 24-55-year-olds are shown in Figures 14 and 15, respectively.

The average total crash involvement rate was 1.93 (SD = 0.17) for 15-17-year-olds and 1.85 (SD = 0.09) for 24-55-year-olds. This teen total involvement rate is only 1.04 times higher than the adult rate. The average fatal/injury crash involvement rate was 0.82 (*SD* = 0.10) for teens and 0.80 (*SD* = 0.05) for adults. The teen fatal/injury involvement rate was again only slightly higher (1.03) than the adult fatal/injury involvement rate.

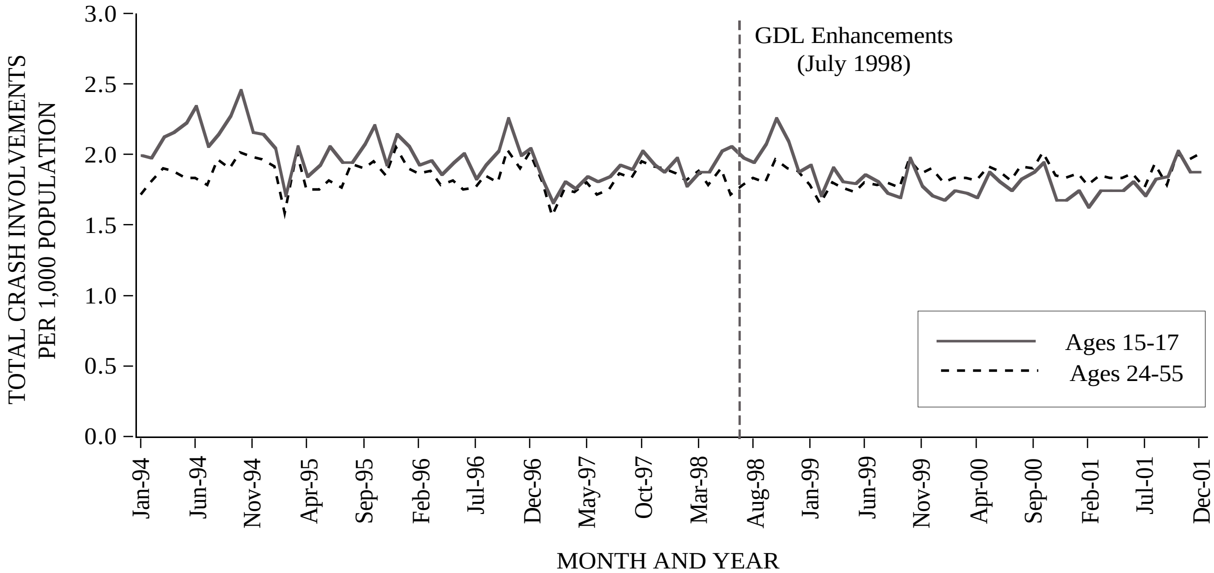


Figure 14. Monthly total crash involvements per 1,000 population for 15-17-year-olds and 24-55-year-olds during January 1994 through December 2001.

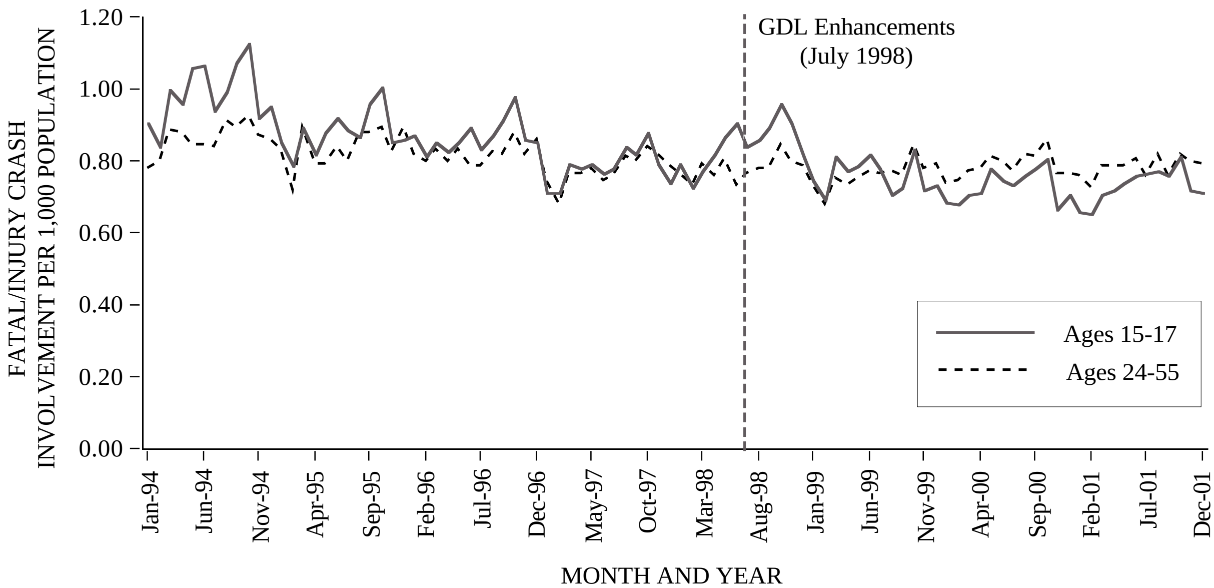


Figure 15. Monthly fatal/injury crash involvements per 1,000 population for 15-17-year-olds and 24-55-year-olds during January 1994 through December 2001.

The results of the time series for both the total and fatal/injury crash involvement series included univariate estimates of gradual-permanent, sudden-temporary, and sudden-permanent intervention effects for both the 15-17-year-old and 24-55-year-old series. These three intervention effects were also evaluated in multivariate series in which the 24-55-year-old crash involvements were used to remove variability in the 15-17-year-old crash involvement rates. The first multivariate series uses the actual July 1998 GDL enhancement implementation date as an intervention point. The second multivariate series uses a January 1999 (6-months subsequent) intervention point and includes parameters for the 6-months before and 6-months after the implementation date to remove any bias associated with the transition effect. The results for the total crash involvement series are shown in Table 9 and the results for the fatal/injury crash involvement series are shown in Table 10. The transition parameters were kept in the models regardless of their level of statistical significance, while all other parameters were evaluated using an alpha level of .05, two-tailed.

Table 9

Total Involvement Crash Rate Model Statistics for Gradual-Permanent, Sudden-Temporary, and Sudden-Permanent Interventions

Intervention	Model component	Parameter	Lag	Estimate	*t*
		Teen univariate			
Gradual-permanent[a]	Intervention	ω	0	0.0919	1.53
		δ	1	-0.8825	-7.26*
	Noise	MA	1	0.4482	4.56*
		MA	12	0.7074	8.22*
Sudden-temporary[a]	Intervention	ω	0	0.0553	1.46
		δ	1	-0.8390	-4.52*
	Noise	MA	1	0.4621	4.68*
		MA	12	0.6127	6.53*
Sudden-permanent[a]	Intervention	ω	0	0.0223	0.27
	Noise	MA	1	0.4588	4.63*
		MA	12	0.6997	8.45*
		Adult univariate			
Gradual-permanent[b]	Intervention	ω	0	-0.0136	-0.21
		δ	1	0.1593	0.02
	Noise	MA	12	0.7153	8.55*
Sudden-temporary[b]	Intervention	ω	0	0.0166	0.25
		δ	1	-0.8949	-0.29
	Noise	MA	12	0.7003	8.84*
Sudden-permanent[b]	Intervention	ω	0	-0.0151	-0.83
	Noise	MA	12	0.7087	8.32*
		Teen multivariate July 1998 intervention point			
Gradual-permanent[a]	Intervention	ω	0	-0.0075	-0.12
		δ	1	-0.4315	-0.06
	Covariate	β	0	0.8175	9.42*
	Noise	MA	1	0.4223	3.93*
		MA	12	0.5630	5.73*
Sudden-temporary[a]	Intervention	ω	0	-0.0149	-0.25
		δ	1	0.0604	0.02
	Covariate	β	0	0.8198	8.72*
	Noise	MA	1	0.4136	3.85*
		MA	12	0.5706	5.93*
Sudden-permanent[a]	Intervention	ω	0	0.0001	0.00
	Covariate	β	0	0.8174	9.43*
	Noise	MA	1	0.4217	3.94*
		MA	12	0.5702	5.83*

Table 9 (continued)

Intervention	Model component	Parameter	Lag	Estimate	*t*
		January 1999 intervention point			
Gradual-permanent[a]	Intervention	ω	0	0.1505	1.52
		δ	1	-0.5570	-1.77
	Covariate	β	0	0.7989	9.39*
	Noise	MA	1	0.4281	3.90*
		MA	12	0.5715	5.77*
	January 98-June 98 Transition		0	0.0951	1.82
	July 98-December 98 Transition		0	0.0937	1.29
Sudden-temporary[a]	Intervention	ω	0	0.2257	3.29*
		δ	1	0.7539	5.93*
	Covariate	β	0	0.8315	8.93*
	Noise	MA	1	0.6274	6.28*
		MA	12	0.5743	5.85*
	January 98-June 98 Transition		0	0.1176	2.73*
	July 98-December 98 Transition		0	0.1604	2.96*
Sudden-permanent[a]	Intervention	ω	0	0.1290	1.26
	Covariate	β	0	0.8075	9.36*
	Noise	MA	1	0.4439	4.16*
		MA	12	0.5745	5.86*
	January 98-June 98 Transition		0	0.0979	1.77
	July 98-December 98 Transition		0	0.1023	1.27

[a]All models included differencing at lags 1 and 12 to produce stationary residuals. [b]Differenced at lag 12.
*$p < .05$, two-tailed.

Table 10

Fatal/Injury Involvement Crash Rate Model Statistics for Gradual-Permanent, Sudden-Temporary, and Sudden-Permanent Interventions

Intervention	Model component	Parameter	Lag	Estimate	*t*
		Teen univariate			
Gradual-permanent	Intervention	ω	0	-0.0105	-0.27
		δ	1	0.5705	0.29
	Noise	MA	1	0.4988	5.08*
		MA	12	0.5693	6.13*
Sudden-temporary	Intervention	ω	0	-0.0188	-0.52
		δ	1	0.3708	0.18
	Noise	MA	1	0.5004	5.17*
		MA	12	0.5636	5.93*
Sudden-permanent	Intervention	ω	0	0.0007	0.02
	Noise	MA	1	0.5103	5.19*
		MA	12	0.5763	5.64*
		Adult univariate			
Gradual-permanent	Intervention	ω	0	0.0147	0.55
		δ	1	-0.8195	-1.16
	Noise	MA	1	0.5933	6.74*
		MA	12	0.6048	6.48*
Sudden-temporary	Intervention	ω	0	0.0145	0.67
		δ	1	-0.6245	-0.77
	Noise	MA	1	0.6537	7.84*
		MA	12	0.5916	5.95*
Sudden-permanent	Intervention	ω	0	0.0020	0.08
	Noise	MA	1	0.6004	6.82*
		MA	12	0.6020	6.51*
		Teen multivariate			
		July 1998 intervention point			
Gradual-permanent	Intervention	ω	0	0.0001	0.00
		δ	1	0.5674	0.00
	Covariate	β	0	0.4253	3.05*
	Noise	MA	1	0.5535	5.57*
		MA	12	0.5534	5.83*
Sudden-temporary	Intervention	ω	0	-0.0282	-0.82
		δ	1	0.1485	0.11

Table 10 (continued)

Intervention	Model component	Parameter	Lag	Estimate	t
	Covariate	β	0	0.4434	2.94*
	Noise	MA	1	0.4864	4.96*
		MA	12	0.5134	5.19*
Sudden-permanent	Intervention	ω	0	-0.0032	-0.09
	Covariate	β	0	0.4115	2.98*
	Noise	MA	1	0.5271	5.18*
		MA	12	0.5050	5.16*
	January 1999 intervention point				
Gradual-permanent	Intervention	ω	0	0.0502	0.91
		δ	1	-0.0961	-0.12
	Covariate	β	0	0.3746	2.85*
	Noise	MA	1	0.6331	6.68*
		MA	12	0.4844	4.70*
	January 98-June 98 Transition		0	0.0761	2.70*
	July 98-December 98 Transition		0	0.0885	2.27*
Sudden-temporary	Intervention	ω	0	0.0347	0.61
		δ	1	1.0342	36.67*
	Covariate	β	0	0.3691	2.53*
	Noise	MA	1	0.5930	6.21*
		MA	12	0.4932	4.77*
	January 98-June 98 Transition		0	0.0723	2.39*
	July 98-December 98 Transition		0	0.0792	1.83
Sudden-permanent	Intervention	ω	0	0.0462	0.88
	Covariate	β	0	0.3719	2.84*
	Noise	MA	1	0.6258	6.44*
		MA	12	0.4807	4.75*
	January 98-June 98 Transition		0	0.0763	2.65*
	July 98-December 98 Transition		0	0.0863	2.17*

Note. All models included differencing at lags 1 and 12 to produce stationary residuals.
$^*p < .05$, two-tailed.

The results of these involvement-based analyses are highly consistent with those based on assigning crashes to the youngest involved driver. Specifically, the multivariate results for total crash involvements indicated a statistically significant sudden-temporary one-time 45.78% increase in teen crashes 6-months subsequent to the GDL program implementation date. The results for fatal/injury crash involvements did not indicate any sudden or gradual change in the fatal/injury crash involvements of the teens at the implementation date or 6-months subsequent. The one difference between these analyses and those based on the age of the youngest involved driver was that no sudden-permanent decrease was found for the univariate adult total crash series. Since the purpose of analyzing involvement rates was merely to determine whether the findings would be consistent with the analyses of crashes categorized based on the age of the youngest involved driver, the effects found for the crash involvement analyses are not quantified here.

Total Crashes for 18-19-Year-Olds

One possible, though unintended, effect of implementing the GDL enhancements could have been to increase the crash rates of 18-19-year-olds due to having the worst drivers self-select themselves out of GDL by waiting until their 18th birthday to obtain a license. At that point they would receive full licensing privileges without the potential benefits of learning under conditions of reduced crash risk. In addition, some of the crash risk of 16-17-year-olds may have been shifted to 18-19-year-olds because these 'older' teen drivers might have needed to transport their younger friends (instead of their younger friends driving themselves) because of the nighttime and passenger restrictions. It is also possible that the program's delay of independent driving may have made 18-19-

year-olds less skillful as independent drivers than they otherwise would have been if the program did not exist and they drove solo earlier. Alternatively, the GDL enhancements could have had residual positive benefits that carried over to 18-19-year-olds as the percentage of drivers in this age group licensed through the GDL program became higher over time. A complete evaluation of the California's GDL program would therefore need to include some analyses of possible positive and negative effects of the program enhancements on the crash rates for 18-19-year-olds.

Plots of total monthly crashes per 1,000 18-19-year-olds and 24-55-year-olds during the period of January 1994 through December 2001 are shown in Figure 16. The average total crash rate per 1,000 18-19-year-olds during this time period was 4.33 (*SD* = 0.35), which is 2.24 times higher than the 15-17-year-old total crash rate of 1.93, and 3.08 times higher than the adult per-capita rate of 1.41 for this same time period. The much higher per capita total crash rate for 18-19-year-olds relative to 15-17-year-olds reflects the fact that a higher percentage of teens in the former age group are licensed and are therefore more likely to be involved in a crash than are persons in the latter group.

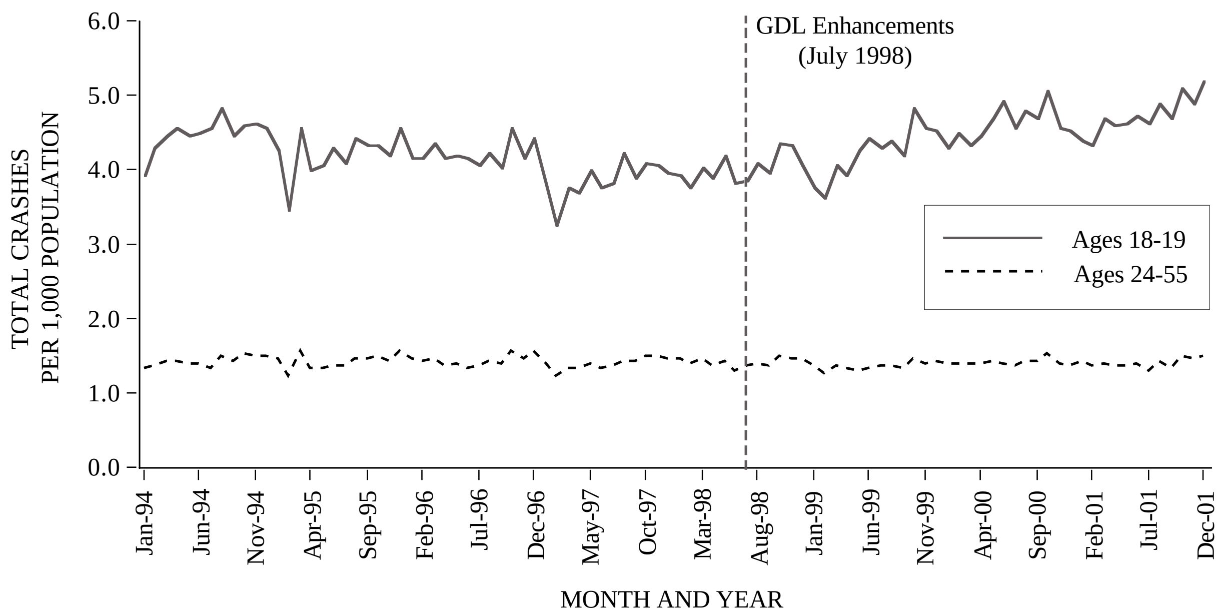


Figure 16. Monthly total crashes per 1,000 population for 18-19-year-olds and 24-55-year-olds during January 1994 through December 2001 by age of youngest driver involved.

Table 11 presents the results of the time series analyses for the gradual-permanent, sudden-temporary, and sudden-permanent intervention types for the 18-19-year-old series, both with and without using the adult rate as a covariate. The analyses were conducted using two different possible intervention points, July 1998 and January 1999, in an attempt to remove any transition effects. The transition parameters were kept in the models regardless of their level of statistical significance, while all other parameters were evaluated using an alpha level of .05, two-tailed. The adult univariate rates are not modeled here because they were modeled earlier (see Table 1).

Table 11

18-19-Year-Old Total Crash Rate Model Statistics for Gradual-Permanent, Sudden-Temporary, and Sudden-Permanent Interventions

Intervention	Model component	Parameter	Lag	Estimate	t
	Teen univariate				
Gradual-permanent	Intervention	ω	0	0.0052	0.02
		δ	1	0.8099	0.14
	Noise	MA	1	0.5660	6.07*
		MA	12	0.6748	8.15*
Sudden-temporary	Intervention	ω	0	-0.0076	-0.05
		δ	1	1.0297	0.03
	Noise	MA	1	0.5051	5.13*
		MA	12	0.5642	5.93*
Sudden-permanent	Intervention	ω	0	-0.0381	-0.21
	Noise	MA	1	0.5675	6.29*
		MA	12	0.6739	8.06*
	Teen multivariate July 1998 Intervention Point				
Gradual-permanent	Intervention	ω	0	0.0524	4.15*
		δ	1	0.9739	81.29*
	Covariate	β	0	3.1340	15.54*
	Noise	MA	1	0.7816	10.10*
		MA	12	0.6860	7.56*
Sudden-temporary	Intervention	ω	0	-0.1566	-1.44
		δ	1	0.1628	0.23
	Covariate	β	0	3.0891	13.01*
	Noise	MA	1	0.5490	5.55*
		MA	12	0.5628	5.47*
Sudden-permanent	Intervention	ω	0	-0.0122	-0.12
	Covariate	β	0	3.0393	13.70*
	Noise	MA	1	0.5785	6.21*
		MA	12	0.6100	6.25*
	January 1999 Intervention Point				
Gradual-permanent	Intervention	ω	0	0.0885	2.91*
		δ	1	0.8908	19.64*
	Covariate	β	0	3.0345	14.46*
	Noise	MA	1	0.6932	8.26*
		MA	12	0.6270	6.58*
	January 98-June 98 Transition		0	0.0982	1.40
	July 98-December 98 Transition		0	0.1028	1.28
Sudden-temporary	Intervention	ω	0	0.0032	0.07
		δ	1	1.1230	1.74
	Covariate	β	0	3.0288	12.57*
	Noise	MA	1	0.5277	5.43*
		MA	12	0.5627	5.10*
	January 98-June 98 Transition		0	0.0767	0.96
	July 98-December 98 Transition		0	-0.0139	-0.17
Sudden-permanent	Intervention	ω	0	0.2696	1.55
	Covariate	β	0	3.0597	13.86*
	Noise	MA	1	0.5902	6.70*
		MA	12	0.5989	6.06*
	January 98-June 98 Transition		0	0.1529	1.59
	July 98-December 98 Transition		0	0.1432	1.09

Note. All models were differenced at lags 1 and 12 to produce stationary residuals.
*$p < .05$, two-tailed.

The multivariate gradual-permanent intervention model was statistically significant at the actual July 1998 implementation date ($\omega = 0.0524$, $t = 4.15$) and also 6-months subsequent in January 1999 ($\omega = 0.0885$, $t = 2.91$). However, the high δ parameter in the July 1998 model is quite close to 1.00 ($\delta = 0.9739$), suggesting that the effect does not reach an asymptote during the time period analyzed (a so-called 'ramp' effect) and indicates possible unreliability in the model parameter estimates. The July 1998 model was therefore rejected. The January 1999 δ value was smaller ($\delta = 0.8908$), indicating an asymptote had been reached by the end of the time series period. The January 1999 gradual-permanent effect represents an increase of 0.0885 total crashes per 1,000 18-19-year-olds the first month (a 2.12% increase over the 4.1667 January 1994 to December 1998 pre-intervention level), and stabilized at a post-intervention level of 0.8104 more crashes per 1,000 capita (a 19.45% increase). Based on the January 1999 to December 2001 average monthly population of 973,173 18-19-year-olds, this translates into about 789 additional crashes per month or 9,464 additional crashes annually.

Fatal/Injury Crashes for 18-19-Year-Olds

Plots of fatal/injury monthly crashes per 1,000 18-19-year-olds and 24-55-year-olds during the period of January 1994 through December 2001 are shown in Figure 17. The average fatal/injury crash rate per 1,000 18-19-year-olds during this time period was 1.87 ($SD = 0.17$), which is 2.28 times higher than the 15-17-year-old fatal/injury crash rate of 0.82, and 3.12 times higher than the adult fatal/injury per-capita rate of 0.60. Again, the higher crash rate for 18-19-year-olds relative to younger teens probably reflects the fact that a higher percentage of 18-19-year-olds are licensed and drive (particularly unsupervised) than are 15-17-year-olds.

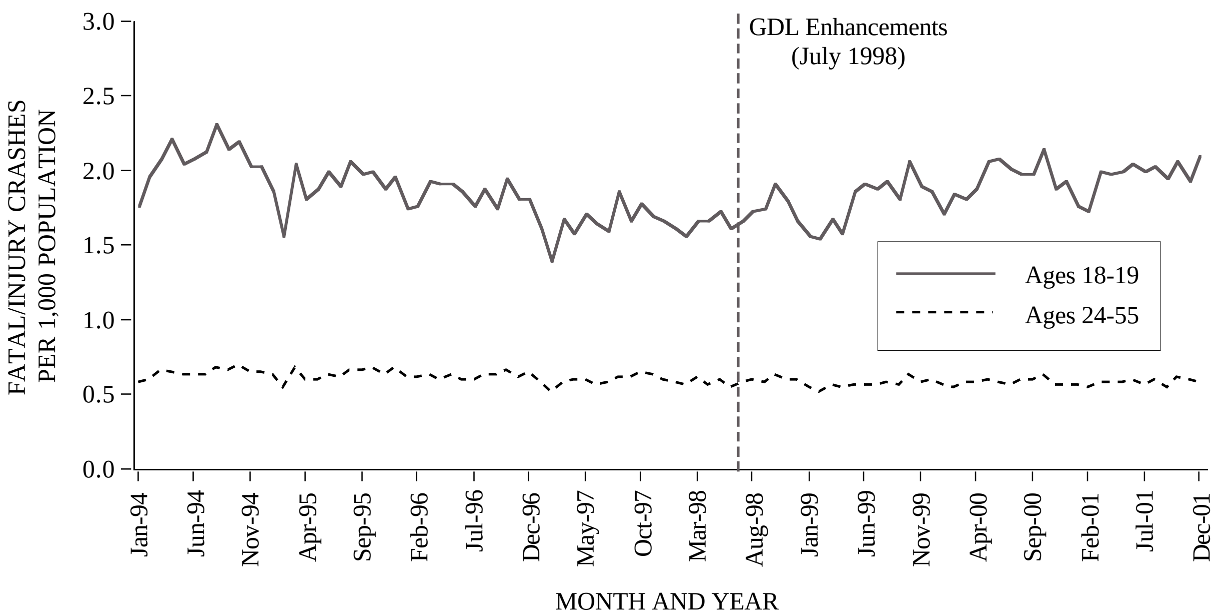


Figure 17. Monthly fatal/injury crashes per 1,000 population for 18-19-year-olds and 24-55-year-olds during January 1994 through December 2001 by age of youngest driver involved.

The time series analysis results for the 18-19-year-old fatal/injury series are shown in Table 12. The transition parameters were kept in the models regardless of their level of statistical significance, while all other parameters were evaluated using an alpha level of .05, two-tailed. None of the intervention parameters were statistically significant for 18-19-year-old fatal/injury crashes at the actual July 1998 implementation date or 6-months subsequent, even after using the adult series as a covariate. This indicates that the program implementation was not associated with a statistically significant sudden or gradual change in the fatal/injury crash rates of 18-19-year-olds.

Table 12

18-19-Year-Old Fatal/Injury Crash Rate Model Statistics for Gradual-Permanent, Sudden-Temporary, and Sudden-Permanent Interventions

Intervention	Model component	Parameter	Lag	Estimate	t
	Teen univariate				
Gradual-permanent[a]	Intervention	ω	0	0.0220	1.45
		δ	1	0.9783	27.69*
	Noise	MA	1	0.6109	6.96*
		MA	12	0.5467	5.78*
Sudden-temporary[a]	Intervention	ω	0	-0.0008	-0.00
		δ	1	-0.4605	-0.01
	Noise	MA	1	0.5462	5.55*
		MA	12	0.4666	4.43*
Sudden-permanent[a]	Intervention	ω	0	0.0342	0.43
	Noise	MA	1	0.5699	6.29*
		MA	12	0.5443	5.76*
	Teen multivariate July 1998 Intervention Point				
Gradual-permanent[b]	Intervention	ω	0	0.0161	1.50
		δ	1	0.9674	27.03*
	Covariate	β	0	3.2253	13.37*
	Noise	MA	1	0.5548	6.15*
		MA	6	0.2764	2.64*
Sudden-temporary[b]	Intervention	ω	0	-0.0461	-0.75
		δ	1	-0.3954	-0.31
	Covariate	β	0	3.0906	12.73*
	Noise	MA	1	0.4875	5.34*
		MA	6	0.2332	2.17*
Sudden-permanent[b]	Intervention	ω	0	0.0139	0.21
	Covariate	β	0	3.1874	12.90*
	Noise	MA	1	0.4780	5.23*
		MA	6	0.2217	2.11*
	January 1999 Intervention Point				
Gradual-permanent[b]	Intervention	ω	0	0.0547	1.58
		δ	1	0.8316	7.41*
	Covariate	β	0	3.2504	13.35*
	Noise	MA	1	0.5751	6.43*
		MA	6	0.2580	2.45*
	January 98-June 98 Transition		0	0.0404	0.71
	July 98-December 98 Transition		0	0.0590	0.93
Sudden-temporary[b]	Intervention	ω	0	-0.1144	-1.43
		δ	1	0.7173	0.84

Table 12 (continued)

Intervention	Model component	Parameter	Lag	Estimate	*t*
	Covariate	β	0	3.0514	12.17*
	Noise	MA	1	0.5080	5.50*
		MA	6	0.2288	2.14*
	January 98-June 98 Transition		0	-0.0279	-0.47
	July 98-December 98 Transition		0	-0.0600	-0.91
Sudden-permanent[b]	Intervention	ω	0	0.0750	0.79
	Covariate	β	0	3.2472	12.71*
	Noise	MA	1	0.5003	5.62*
		MA	6	0.2221	2.11*
	January 98-June 98 Transition		0	0.0296	0.45
	July 98-December 98 Transition		0	0.0301	0.37

[a]Differenced at lags 1 and 12 to produce stationary residuals. [b]Differenced at lag 1.
*$p < .05$, two-tailed.

DISCUSSION

This study analyzed several different crash types and age-groups, various intervention models, and flexible intervention start points to determine whether the enhancements made to the California teen licensing program in July 1998 resulted in crash reductions for teen drivers. The results are summarized below:

- No overall reduction in total crashes or fatal/injury crashes was found immediately following program implementation or beginning 6 months later. This outcome was the same even when transition components were added to the models to adjust for the influence of the influx of teen licensees before the implementation date, when the adult series was included as a control variable, when only 16-year-old driver crashes were analyzed, and when the rates were calculated as crash involvements rather than being based on the youngest involved driver. However the program was found to be associated with a 19.45% gradual-permanent increase in total crashes for 18-19-year-olds 6 months after the program was implemented (about 9,464 additional crashes per year). No significant effect was found in the 18-19-year-olds fatal/injury crashes.

- The 12-month nighttime restriction was associated with a sudden-permanent 0.44% reduction in total crashes occurring during the hours of midnight to 5:00 a.m. for 15-17-year-olds starting 1-year subsequent to the implementation of the nighttime restriction. The results also suggested a marginally significant sudden-permanent 0.45% reduction in their nighttime fatal/injury crashes starting 1-year subsequent to the program implementation. These effects translate into savings of 153 total crashes and 68 fatal/injury crashes annually for 15-17-year-olds. These crash savings estimates are based on an assumption that the GDL night driving restriction did not increase daytime crashes.

- The 6-month passenger restriction was associated with a marginally significant sudden-permanent 2.52% reduction in 15-17-year-old total teen passenger crashes, and a significant gradual-permanent reduction stabilizing at -6.43% in fatal/injury passenger crashes when using an intervention date 1-year subsequent to the program start date. These effects equate to savings of 878 total crashes and 975 fatal/injury crashes annually for 15-17-year-olds. These crash savings estimates are based on an assumption that the GDL passenger restriction did not cause an increase in non-passenger crashes for the 15-17-year-old age group.

The fact that no overall reductions were found in teen total or fatal/injury crash rates from the program start date or from a 6-months subsequent date is not surprising given the Williams et al. (2002) findings indicating that many teens were applying for their instruction permit earlier to avoid delaying licensure, and that only small increases were found in the percentages of teens receiving additional hours and miles of supervised on-the-road practice during this longer instruction permit period. In addition, the reductions associated with the nighttime and passenger restrictions were small and occurred some months later in time and therefore would not have helped detect an effect using the time periods analyzed for the overall analyses.

The fact that an increase was found in total crashes for 18-19-year-olds suggests that GDL programs may have unintended negative consequences for this and possibly other age groups. One possibility for this finding is that any positive effects of the program may not continue into later years and that 16-17-year-olds under the program might not be as safe and skilled at age 18 as they would have been without the GDL restrictions. The increase in 18-19-year-old crash rates could also be due to a higher percentage of that age group being licensed due to younger teens waiting to license until age 18 to avoid the program. In any case, it is recommended that 18-19-year-olds not be used as a comparison group for evaluations of GDL programs because it appears that drivers in this age group are impacted by such programs.

It should be noted that it is possible that the program impacted the crash rates for 24-55-year-olds. This age group was selected as a control variable based on an assumption that it would have been impacted by the same extraneous variables that impacted the teen crash rates and also that it would not have been influenced by the program. It is possible that the latter assumption may not be completely true. For example, it is possible that the program may have resulted in more driving among adults due to their needing to transport their teens for a longer period of time than before the program, especially during late night hours. This could have elevated the crash rates for adults by an unknown amount during the post period above what they would have been had the program not been implemented. This would have tended to bias the analyses that included the adult series as a control variable in favor of finding a positive impact of the program on the crash rates of 15-17-year-olds. However any such biasing influence is believed to be minimal. The analyses of the nighttime and passenger restrictions would not have been subject to any such bias because the crash rates of adults were not used as a control variable in those analyses.

Because the post-program crash rates for teens were compared to their pre-program rates, and these pre-program rates already reflected the influence of crash reductions associated with the original teen licensing program evaluated by Hagge and Marsh (1988), any benefit of the program enhancements made in 1998 was expected to be only marginal incremental reductions in crash rates. Indeed, the observed effects for the nighttime and passenger restrictions were modest in size. If this evaluation had compared the crash rates under this enhanced program with all of its components to some theoretical set of teen crash rates for drivers under no program, it is much more likely that significant and larger decreases in overall total and fatal/injury crash rates associated with the program would have been found.

Finding reductions in total and fatal/injury nighttime crashes is consistent with results from other states that have adopted nighttime restrictions (Ferguson et al., 1996; McKnight et al., 1983). The use of a 1-year delayed intervention date for analyzing the effects of the nighttime and passenger restrictions seems justified because it both reduced transition bias associated with the increase in teen licensure around the time the enhancements were implemented and allowed time for more teens to be fully under the program requirements. This latter issue is especially relevant for evaluating the restrictions because they do not take effect until the teens complete the 6-month instruction permit period. The percentage reductions associated with the nighttime restriction were, however, quite small. Larger nighttime crash reductions may have been realized if the nighttime restriction began at an earlier time (e.g., 11:00 p.m. or earlier), as has been suggested by traffic safety experts (McKnight, 1986; Williams & Mayhew, 2003). In addition, although around 90% of teens complied for at least the first 6 months of the restriction, only 60% of teens were found to have not driven after midnight for their first full year after licensure (Williams et al., 2002). Clearly if parents could be motivated to not permit driving for the full term of the restriction, even larger reductions in nighttime teen crashes might be realized.

California was the first state to implement a meaningful teen passenger restriction (Williams et al., 2002). Finding that the passenger restriction was associated with modest, but significant reductions in both total and fatal/injury crashes is noteworthy because it indicates that passenger restrictions are effective components of GDL programs. Although compliance with the 6-month passenger restriction was not found to be very high (around 50%), not transporting other teenagers during the first 6-months of driving represented the largest actual change in behavior before and after the GDL enhancements were implemented (Williams et al., 2002). Therefore it is not surprising that the effects of the passenger restriction were larger than those for the nighttime restriction. Given the high crash risk of teen drivers when they transport other teenagers, finding ways to increase the willingness of parents to enforce the passenger restriction would likely result in additional crash savings.

Although the California GDL program evaluated in this report is considered to be one of the strongest in the United States, there are additional features that could be added or changed that may serve to strengthen the program even further. In addition to starting the nighttime restriction at an earlier time and finding ways to increase compliance with the nighttime and passenger restrictions, the program could be improved by making a teen's advancement from one stage of licensure to another contingent upon maintaining a crash- and violation-free driving record, and by tying the passenger and nighttime restrictions to the intermediate licensing stage rather than to a set period of time (McKnight, 1986). Furthermore, compliance with the nighttime and passenger restrictions could be increased by allowing law enforcement officers to stop teens simply because they believe they are violating these restrictions (i.e., primary enforcement).

Other authors (e.g., Mayhew & Simpson, 2002) have recommended that driver education and training be integrated into GDL programs so that they are multi-staged, with a basic driver education course before teens learn how to drive and an advanced course after they have gained some experience driving on the road. More complex topics, such as hazard perception, might be better taught in the advanced course where experience on the road might make these topics more understandable. Results of a recent evaluation (Masten & Chapman, 2003) showing that home-study driver education courses were just as effective as classroom-based courses for teaching basic driver education content may provide a means for removing some of the potential roadblocks for integrating such a two-staged driver education and training system with California's GDL program. The use of home-study driver education for the first stage of a tiered driver education and training program may also increase parental involvement in their teen's early driving experience, and motivate them to more fully enforce the GDL restrictions.

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APPENDIX

Provisional License for Minors: Distinctive Driver's License

12814.6. (a) ( )1 ***Except as provided in Section 12814.7***, any driver's license issued to a person at least 16 years of age but under 18 years of age shall be issued pursuant to the provisional licensing program contained in this section. The program shall consist of all of the following components:

(1) Upon application for an original license, the applicant shall be issued an instruction permit pursuant to Section 12509. A person who has in his or her immediate possession a valid permit issued pursuant to Section 12509 may operate a motor vehicle, other than a motorcycle or motorized bicycle, ( )2 ***only when the person is either taking the driver training instruction referred to in paragraph (3) or practicing that instruction, provided the person is accompanied by, and is under the immediate supervision of, a California licensed driver 25 years of age or older*** whose driving privilege is not on probation. The age requirement of this paragraph does not apply if the licensed driver is the parent, spouse, or guardian of the permitholder or is a licensed or certified driving instructor.

(2) The person shall hold an instruction permit for not less than six months prior to applying for a provisional driver's license.

(3) The person shall have complied with one of the following:

(A) Satisfactory completion of approved courses in automobile driver education and driver training maintained pursuant to provisions of the Education Code in any secondary school of California, or equivalent instruction in a secondary school of another state.

(B) Satisfactory completion of six hours or more of behind-the-wheel instruction by a driving school or an independent driving instructor licensed under Chapter 1 (commencing with Section 11100) of Division 5 and either an accredited course in automobile driver education in any secondary school of California pursuant to provisions of the Education Code or satisfactory completion of equivalent professional instruction acceptable to the department. To be acceptable to the department, the professional instruction shall meet minimum standards to be prescribed by the department, which standards shall be at least equal to the requirements for driver education and driver training contained in the rules and regulations adopted by the State Board of Education pursuant to the Education Code. A person who has complied with this subdivision shall not be required by the governing board of a school district to comply with subparagraph (A) in order to graduate from high school.

(C) No student shall take driver training instruction, unless he or she is taking driver education at the same time or has successfully completed driver education.

(4) The person shall complete 50 hours of supervised driving practice prior to the issuance of a provisional license, which is in addition to any other driver training instruction required by law. Not less than 10 of the required practice hours shall include driving during darkness, as defined in Section 280. Upon application for a provisional license, the person shall submit to the department the certification of a parent, spouse, guardian, or licensed or certified driving instructor that the applicant has completed the required amount of driving practice and is

prepared to take the department's driving test. A person without a parent, spouse, guardian, or who is an emancipated minor, may have a licensed driver 25 years of age or older or a licensed or certified driving instructor complete the certification. This requirement does not apply to motorcycle practice.

(5) The person shall successfully complete an examination required by the department. Before retaking a test, the person shall wait for not less than one week after failure of the written test and for not less than two weeks after failure of the driving test.

(b) ( )3 ***Except as provided in Section 12814.7***, the provisional driver's license shall be subject to all of the following restrictions:

(1) Except as specified in paragraph (3), during the first six months after issuance of a provisional license the licensee shall not do any of the following unless accompanied and supervised by a licensed driver who is the licensee's parent or guardian, a licensed driver who is 25 years of age or older, or a licensed or certified driving instructor:

(A) Drive between the hours of ( )4 ***12 midnight*** and 5 a.m.

(B) Transport passengers who are under 20 years of age.

(2) During the second six months after issuance of a provisional license the licensee may transport passengers under the age of 20 years between the hours of ( )5 5 a.m. and ***12 midnight*** without supervision. This driving time restriction shall not modify or alter any local ordinance that restricts or prohibits cruising during specified proscribed hours. However, the restriction imposed under subparagraph (A) of paragraph (1) shall continue to apply during this period.

(3) A licensee may drive between the hours of ( )4 ***12 midnight*** and 5 a.m. or transport an immediate family member without being accompanied and supervised by a licensed driver who is the licensee's parent or guardian, a licensed driver who is 25 years of age or older, or a licensed or certified driving instructor, in the following circumstances:

(A) Medical necessity of the licensee when reasonable transportation facilities are inadequate and operation of a vehicle by a minor is necessary. The licensee shall keep in his or her possession a signed statement from a physician familiar with the condition, containing a diagnosis and probable date when sufficient recovery will have been made to terminate the necessity.

(B) Schooling or school-authorized activities of the licensee when reasonable transportation facilities are inadequate and operation of a vehicle by a minor is necessary. The licensee shall keep in his or her possession a signed statement from the school principal, dean, or school staff member designated by the principal or dean, containing a probable date that the schooling or school-authorized activity will have been completed.

(C) Employment necessity of the licensee when reasonable transportation facilities are inadequate and operation of a vehicle by a minor is necessary. The licensee shall keep in his or her possession a signed statement from the employer, verifying employment and containing a probable date that the employment will have been completed.

(D) Necessity of the licensee or the licensee's immediate family member when reasonable transportation facilities are inadequate and operation of a vehicle by a minor is necessary to transport the licensee or the licensee's immediate family member. The licensee shall keep in his or her possession a signed statement from a parent or legal guardian verifying the reason and containing a probable date that the necessity will have ceased.

(E) The licensee is an emancipated minor.

(c) A law enforcement officer shall not stop a vehicle for the sole purpose of determining whether the driver is in violation of the restrictions imposed under subdivision (b).

(d) (1) Upon a finding that any licensee has violated paragraph (1) or (2) of subdivision (b), the court shall impose one of the following:

(A) Not less than eight hours nor more than 16 hours of community service for a first offense and not less than 16 hours nor more than 24 hours of community service for a second or subsequent offense.

(B) A fine of not more than thirty-five dollars ($35) for a first offense and a fine of not more than fifty dollars ($50) for a second or subsequent offense.

(2) If the court orders community service, the court shall retain jurisdiction until the hours of community service have been completed.

(3) If the hours of community service have not been completed within 90 days, the court shall impose a fine of not more than thirty-five dollars ($35) for a first offense and not more than fifty dollars ($50) for a second or subsequent offense.

(e) No conviction of paragraph (1) or (2) of subdivision (b), when reported to the department, shall be disclosed as otherwise specified in Section 1808 or constitute a violation point count value pursuant to Section 12810.

(f) Any term of restriction or suspension of the driving privilege imposed on a person pursuant to this subdivision shall remain in effect until the end of the term even though the person becomes 18 years of age before the term ends.

(1) The driving privilege shall be suspended when the record of the person shows one or more notifications issued pursuant to Section 40509 or 40509.5. The suspension shall continue until any notification issued pursuant to Section 40509 or 40509.5 has been cleared.

(2) A 30-day restriction shall be imposed when a driver's record shows a violation point count of two or more points in 12 months, as determined in accordance with Section 12810. The restriction shall require the licensee to be accompanied by a licensed parent, spouse, guardian, or other licensed driver 25 years of age or older, except when operating a class M vehicle, or so licensed, with no passengers aboard.

(3) A six-month suspension of the driving privilege and a one-year term of probation shall be imposed whenever a licensee's record shows a violation point count of three or more points in 12 months, as determined in accordance with Section 12810. The terms and conditions of probation shall include, but not be limited to, both of the following:

(A) The person shall violate no law which, if resulting in conviction, is reportable to the department under Section 1803.

(B) The person shall remain free from accident responsibility.

(g) Whenever action by the department under subdivision (f) arises as a result of a motor vehicle accident, the person may, in writing and within 10 days, demand a hearing to present evidence that he or she was not responsible for the accident upon which the action is based. Whenever action by the department is based upon a conviction reportable to the department under Section 1803, the person has no right to a hearing pursuant to Article 3 (commencing with Section 14100) of Chapter 3.

(h) The department shall require any person whose driving privilege is suspended or revoked pursuant to subdivision (f) to submit proof of financial responsibility as defined in Section 16430. The proof of financial responsibility shall be filed on or before the date of reinstatement following the suspension or revocation. The proof of financial responsibility shall be maintained with the department for three years following the date of reinstatement.

(i) Notwithstanding any other provision of this code, the department may issue a distinctive driver's license, which displays a distinctive color or a distinctively colored stripe or other distinguishing characteristic, to persons at least 16 years of age and older but under 18 years of age, and to persons 18 years of age and older but under 21 years of age, so that the distinctive license feature is immediately recognizable. The features shall clearly differentiate between drivers' licenses issued to persons at least 16 years of age or older but under 18 years of age and to persons 18 years of age or older but under 21 years of age.

If changes in the format or appearance of drivers' licenses are adopted pursuant to this subdivision, those changes may be implemented under any new contract for the production of ( )6 drivers' licenses entered into after the adoption of those changes.

(j) The department shall include, on the face of the provisional driver's license, the original issuance date of the provisional driver's license in addition to any other issuance date.

(k) This section shall be known and may be cited as the Brady-Jared Teen Driver Safety Act of 1997.
Amended Sec. 8, Ch. 760, Stats. 1997. Effective January 1, 1998.
Amended Sec. 19, Ch. 1035, Stats. 2000. Effective January 1, 2001.
Amended Sec. 13.5, Ch. 758, Stats. 2002. Effective January 1, 2003.
The 2002 amendment added the italicized material, and at the point(s) indicated, deleted the following:
1. "Notwithstanding any other provision of law"
2. "subject to Section 12509 only if that person is accompanied by, and under the immediate supervision of, a driver who is 25 years of age or older, who holds a driver's license issued under this code, and "
3. "Commencing July 1, 1998,"
4. "12:00 a.m."
5. "12:00 a.m."
6. "driver's"